

**EVALUATION OF CARBON SEQUESTRATION
POTENTIAL UNDER DIFFERENT LAND USE SYSTEMS
AT RAJIV GANDHI SOUTH CAMPUS, BHU,
BARKACHHA, MIRZAPUR (U.P.)**

काशी हिन्दू
विश्वविद्यालय



BANARAS HINDU
UNIVERSITY

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

Master of Science (Agriculture)

in

Agroforestry

Submitted by

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Dear Sir,

I have great pleasure in forwarding the thesis entitled “Evaluation of carbon sequestration potential under different land use system at Rajiv Gandhi South Campus, BHU, Barkachha, Mirzapur ” submitted by **Bijoya Mondal, ID. No. AGF-13177**, in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture)** in **Agroforestry**.

I certify that the work has been carried out under my guidance and the data forming the basis of this thesis, to the best of our knowledge are original and genuine and no part of the work has been submitted for any other degree or dissertation.

Thanking you.

Yours faithfully

Forwarded by:

(Avijit Sen)
(Supervisor)

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BARKACCHA, MIRZAPUR**

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CONTENTS

Chapter No.	Detail	Page(s)
I	Introduction	1-4
II	Review of Literature	5-20
III	Material and Methods	21-44
IV	Experimental Findings.....	45-64
V	Discussion	65-74
VI	Summary and Conclusion	75-78
	Bibliography	i-ix
	Appendices	i-vi

LIST OF TABLES

Table No.	Particulars	Page No.
Table 3.1	Land use and other agricultural characteristics of the study area - Rajiv Gandhi South Campus.....	24
Table 3.2	Physico-chemical properties the soil of experimental	26
Table 3.3	Details of treatments (experiment-1).....	27
Table 3.4	Details of treatments (experiment-2).....	28
Table 3.5	Treatment combinations	29
Table 3.6	Details of layout (experiment -1).....	29
Table 3.7	Details of layout (experiment -2)	30
Table 3.8	Structures and composition of prevalent under different land use systems at RGSC, BHU, Barkachha, Mirzapur	31
Table 3.9	ANOVA Table (Experiment -1)	44
Table 3.10	ANOVA Table (Experiment -2)	44
Table 4.1	Effect of land use system on amount and rate of biomass accumulation at RGSC, BHU, Barkachha, Mirzapur (U.P.)	48
Table 4.2	Effect of land use system amount and rate of carbon sequestration at RGSC, BHU, Barkachha, Mirzapur (U.P.)	50
Table 4.3	Effect of land use system on amount and rate of CO ₂ sequestration and carbon credit at RGSC, BHU, Barkachha, Mirzapur (U.P.)	52
Table 4.4	Effect of land use system and altitudinal ranges on soil organic carbon (%), bulk density (g cm ⁻³), soil organic carbon density(t ha ⁻¹ yr ⁻¹) and total soil carbon stock (soil + leaf litter) (t ha ⁻¹) at RGSC, BHU, Barkachha, Mirzapur (U.P.)	54

Table No.	Particulars	Page No.
Table 4.5	Effect of interaction between different land use systems and soil depth on soil organic carbon density in at RGSC, BHU, Barkachha, Mirzapur (U.P.)	56
Table 4.6	Effect of interaction between different land use systems and soil depth on soil bulk density in at RGSC, BHU, Barkachha, Mirzapur (U.P.)	58
Table 4.7	Influence of different land use systems on leaf litter – its accumulation (fresh and dry weight basis) and total carbon sequestration under at RGSC, BHU, Barkachha, Mirzapur (U.P.).....	60
Table 4.8	Comparison criteria for economic analysis of different land use systems in experiment duration at RGSC, BHU, Barkachha, Mirzapur (U.P.)	63

LIST OF FIGURES

Figure No.	Particulars	After Page No.
Fig 3.1	Mean month-wise meteorological data during experiment, 2014-15.....	22
Fig 3.2	Location of Rajiv Gandhi South Campus	24

ABBREVIATIONS

\$	Dollar
%	Per cent
@	At the rate of
AF	Agroforestry
AFS	Agroforestry systems
AFTA	Association for Temperate Agroforestry
AH	Agri-horticulture
AHS	Agri-horti-silviculture
approx	Approximately
AS	Agri-silviculture
BD	Bulk density
C ha ⁻¹	Carbon per hectare
C ha ⁻¹ yr ⁻¹	Carbon per hectare per year
CD	Critical difference
CH ₄	Methane
cm	Centimeter
CO ₂	Carbon dioxide
CSP	Carbon sequestration potential
DBH	Diameter at breast height
DOE	Department of Energy
<i>et al.</i>	And co-workers
FCCC	Framework Convention on Climate Change
g	gram
g Kg ⁻¹	Gram per kilogram
gcm ⁻³	Gram per centimeter cube
GHG	Green House gas
GHGs	Green house gasses
Gt	Giga tonne
ha	Hectare (10,000 m ²)
HP	Horti-pastoral
i.e	That is
IPCC	Intergovernmental Panel on Climate Change
Kg cm ⁻²	Kilogram per square centimeter
Kg CO ₂ ha ⁻¹ day ⁻¹	Kilogram carbon dioxide per hectare per day
Kg ha ⁻¹ day ⁻¹	Kilogram per hectare per day
Kg ha ⁻¹ Yr ⁻¹	Kilogram per hectare per year
Kg m ⁻²	Kilogram per square meter
Km	Kilometer
m	Meter

M ha	Million hectare
m.a.m.s.l	meter above mean sea level
MAP	Mean Annual precipitation
MAT	Mean Annual Temperature
Mg c ha ⁻¹	Mega gram carbon per hectare
Mg c ha ⁻¹ yr ⁻¹	Mega gram carbon per hectare per year
Mg ha ⁻¹	Mega gram per hectare
Mg km ⁻¹ yr ⁻¹	Mega gram per kilometer per year
MMTCY ⁻¹	Million metric tonne carbon per year
MT	Million tons
N	Nitrogen
N ₂ O	Nitrous oxide
NE	North East
NRCS	National Resource Conservation Services
°C	Degree Celsius
OC	Organic carbon
P	Phosphorus
PA	Pure agriculture
Pg	Petagram
PG	Pure grassland
Pg C	Peta gram carbon
Pg c yr ⁻¹	Peta gram carbon per year
PP	Pure plantation
PPM	Part Per Million
Rs. ha ⁻¹ yr ⁻¹	Rupees per hectare per year
SOC	Soil Organic carbon
SOM	Soil organic matter
SP	Silvi-pastoral
t c ha ⁻¹	Tonne Carbon per hectare
t c ha ⁻¹ yr ⁻¹	Tonne Carbon per hectare per year
Tg	Tera gram
Tg C yr ⁻¹	Teragram Carbon per year
UNCED	United Nations Conference on Environment and Development
US\$	United State's dollar
USA	United States of America
USDA	United State Department of Agriculture,
WANA	West Asia and North Africa

One of the most alarming issues today is climate change, which is brought about by the increasing concentration of the greenhouse gases in the atmosphere. Carbon dioxide (CO₂) is a major GHG and its concentration build-up is accelerated by human activities such as burning of fossil fuels and deforestation. To reduce this major greenhouse gas in the atmosphere, there is a need to increase the sink in the form of biomass (Zhao *et al.* 2014). One of the approaches to reduce CO₂ concentration in the atmosphere is carbon (C) sequestration by storing it in trees and other plants through photosynthesis. This concept became widely known because the Kyoto Protocol has proposed an approach called as Land Use, Land Use Change and Forestry (LULUCF), which allows use of carbon sequestration through afforestation and reforestation as a form of GHG offset activity. The Marrakesh Accords in 2001 determined more detailed rules of LULUCF and added forest management, crop management, grazing land management, and revegetation as LULUCF activities. This enables agro-forestry to be an activity of carbon sequestration under the Kyoto Protocol, and since then, carbon sequestration potential of agro-forestry systems has attracted attention from both industrialized and developing countries (Nair *et al.* 2010).

The atmospheric concentration of CO₂ has increased by 31% since 1750 (Lal, 2004). According to IPCC (2007) reports, the atmospheric CO₂ concentration is around 390 ppm, which was around 280 ppm prior to industrial revolution (IPCC, 2007). According to future emission scenario (Shukla *et al.* 2003), CO₂ emission shall continue to dominate national GHG emission with its share reaching 74% in 2030.

Biomass and carbon (C) storage in forest ecosystems play an important role in global carbon cycle (Goodale *et al.* 2002; Houghton 2005; Li *et al.* 2011; Zhao *et al.* 2014) because forest ecosystems act as a major carbon sink and store more carbon per unit area than any other terrestrial ecosystem (Houghton 2007). Forests act as an effective measure to mitigate elevated CO₂ concentrations by increasing forested land area (Taylor *et al.* 2007). Forests cover 4.03 billion hectares globally, approximately 30 % of the Earth's total land area (FAO 2010), which account for 80 % of the Earth's total plant biomass (Kindermann *et al.* 2008) which in turn contain more carbon in biomass and soils than stored in the atmosphere (Pan *et al.* 2011).

The tree components in agroforestry systems can be significant sinks of atmospheric carbon due to their fast growth and high productivity. Thus, promoting agroforestry can be one of the options to deal with problems related to land use and CO₂ induced global warming. The amount of carbon sequestered, however, will largely depend on the agroforestry system, its structure and function which to a great extent, are determined by environmental and socio-economic factors. Also tree species and system management can influence carbon storage in agroforestry systems (Albrecht and Kandji, 2003).

Agro-forestry provides a unique opportunity to combine the twin objectives of climate change adaptation and mitigation. Although Agro-forestry systems are not primarily designed for carbon sequestration, there are many recent studies that substantiate the evidence that Agro-forestry systems can play a major role in storing carbon in aboveground biomass (Sathaye *et al.* 2001) and in soil and in belowground biomass (Nair *et al.* 2009). Some of the earliest studies of potential carbon storage in Agro-forestry systems and alternative land use systems for India had estimated a sequestration potential of

68-228 Mg C ha⁻¹(Dixon *et al.* 1994), 25 t C ha⁻¹ over 96 M ha of land .However, this value varies in different regions depending on the biomass production

Agro-forestry has carbon storage potential in its multiple plant species and soil, high applicability in agricultural land, and indirect effects such as decreasing pressure on natural forest or soil erosion (Nair and Nair 2003; Lal 2004a; Montagnini and Nair 2004). Some studies of specific agro-forestry practices proved the potential of carbon sequestration and its benefits, such as the Indonesian home garden systems (Roshetko *et al.* 2002). However, very few such studies have been reported regarding carbon sequestration potential of agro-forestry systems in semi-arid and arid regions. In addition to already existing indigenous agro-forestry systems, improved practices and technologies are now being expanded into these dry regions for perceived benefits such as arresting desertification, reducing water and wind erosion hazards, and improving biodiversity (Droppelmann *et al.* 2000; Gordon *et al.* 2003). In this scenario, it is imperative that carbon sequestration potential of agro-forestry practices in these regions is investigated. If the majority of the people who are subsistence farmers can receive even small amount of carbon payments through their agro-forestry practices, it would be a substantial contribution to their economic welfare and overall development of the region. Thus, an analysis of the carbon sequestration potential of various agro-forestry practices (traditional and newly introduced) in the region is timely. There is considerable interest to increase the carbon storage capacity of terrestrial vegetation through land-use practices such as aforestation, reforestation, and natural regeneration of forests, silvicultural systems and agro-forestry (Brown, 1996).

Keeping these in view, the present investigation entitled “Evaluation of carbon sequestration potential under different land use systems” was carried out during *Kharif* and *Rabi* seasons of 2014-2015, at Rajiv Gandhi South Campus, Mirzapur, Uttar Pradesh, with the following objectives:

1. Quantification of carbon sequestration under different land use systems
2. To find out the biological yield from the different land use systems
3. To identify the different land use systems having high carbon storage and monetary returns.



An attempt has been made in this chapter to review the research work done related to the topic on carbon sequestration potential which was carried out during *Kharif* and *Rabi* seasons of 2014-2015, at Rajiv Gandhi South Campus, Mirzapur, Uttar Pradesh under various heads and sub-heads.

2.1 CARBON SEQUESTRATION - ITS NECESSITY AND CURRENT STATUS

The rate of increase in global temperature has been 0.158°C per decade since 1975. In addition to the sea-level rise of 15–23 cm during the twentieth century (IPCC 2007), global surface temperature has also increased by 0.88°C since the late nineteenth century. 11 out of the 12 warmest years on record have occurred since 1995 (IPCC 2007). Later on Pawan (2014) revealed that average rise in global surface temperature would be 1 to 4.5°F (0.6°C to 2.5°C) in the next fifty years and 2.2°F to 10°F in the next 100 years with significant regional variations. Furthermore, IPCC (2013) reported in the recently released Fifth Assessment Report that land and ocean surface temperatures have increased globally by nearly 1°C since 1901 (0.89°C global average), mainly as a result of anthropogenic activities. The IPCC also predicts that a global mean temperature change of +0.3 to +0.7°C is likely to take place between 2016 and 2035. Similarly, WMO (2012) estimated that CO₂ concentration in the atmosphere had increased from 280 ppm in 1850 to nearly 400 ppm in 2013-14. Global greenhouse gas emissions are estimated at 50.1 (GtCO₂) (with a 95 % uncertainty range of 45.6 to 54.6). This is already 14 % higher than the median estimate 44 (GtCO₂) of the 2020 emission level. The debate on the build up of atmospheric greenhouse gases and their role in global warming, however, was extended to the third session of the

conference of the UNFCCC in 1997 in Kyoto, Japan. Protocol was signed by all the participating countries to find ways of reducing greenhouse gases concentrations in the atmosphere. Malhi *et al.* 2008 observed that the trees could capture and store atmospheric CO₂ in vegetation, soils, and biomass products. Agroforestry facilitates carbon sequestration under the afforestation and reforestation activities that have been recognized as GHG-mitigating strategies under the Kyoto Protocol; thus, agroforestry systems started attracting attention as a c-sequestration strategy from both industrialized and developing countries.

The Kyoto Protocol of UNFCCC went into force on 16th February 2005 by imposing limits on emission of CO₂ and other greenhouse gases (Rawat, 2005) . The forestry has been recognized as a means to reduce carbon dioxide (CO₂) emissions as well as enhancing carbon sinks (Murthy *et al.* 2013) . Vashum and Jay Kumar (2012) reported that forest ecosystem plays an important role in the global carbon cycle by sequestering a substantial amount of carbon dioxide from the atmosphere. Carbon sequestration is a mechanism for the removal of carbon from the atmosphere by storing it in the biosphere (Chavan and Rasal, 2012). Average carbon sequestration potential in agroforestry of India has been estimated to be 25 t ha⁻¹ over 96 m ha area (Sathaye and Ravindranath 1998). Oelbermann *et al.* (2004) reported that above ground biomass has potential of sequestering 2.1×10^9 Mg C yr⁻¹ in the tropical and 1.9×10^9 Mg C yr⁻¹ in the temperate regions. Similarly, Albrecht and Kandji (2003) estimated that the carbon storage potential of agroforestry systems lie between 12 and 228 Mg ha⁻¹ with a median value of 95 Mg ha⁻¹. Agroforestry systems (AFS) have higher carbon (C) stocks than agricultural monocultures, and expansion of agroforestry practices could raise the C stocks of African terrestrial systems. On a global level, Dixon *et al.*

(1993) estimated a sequestration potential by forestry and agroforestry practices of about 1 Pg of C per year, corresponding to about 3.7 Pg CO₂, or roughly one-eighth of annual global emissions.

Nair *et al.* (2009) reported that the carbon sequestration ranges between 1.50–6.55 Mg C ha⁻¹yr⁻¹ for tropical Agroforestry (AFS). According to the IPCC (2000) tropical forests are the largest carbon stock in vegetation, while boreal forests represent the largest carbon stock in soils.

Mutuo (2005) observed that the agroforestry systems increase above ground and soil carbon stock and reduce soil degradation, as well as mitigate greenhouse gas emissions. In the humid tropics, the potential of agroforestry tree-based systems to sequester carbon in vegetation can be over 70 Mg C ha⁻¹ and up to 25 Mg ha⁻¹ in the top 20 cm of soil. In degraded soils of the sub-humid tropics, improved fallow agroforestry practices have been found to increase top soil C stocks by upto 1.6 Mg C ha⁻¹ y⁻¹.

2.2 METHODS FOR QUANTIFICATION OF CARBON SEQUESTRATION IN DIFFERENT LAND USE SYSTEMS

Dixon *et al.* (1994) showed that carbon stock in each tree could be estimated by multiplying the total above ground biomass of individual tree with carbon fraction 0.5.

Brown *et al.* (1997) gave allometric equation to estimate biomass (kg) of above-ground vegetation. That biomass regression equation was used for most species and the equation was $\exp \{-2.134 + 2.530 \times \ln \text{DBH}\}$ (DBH=diameter at breast height).

Cairns *et al.* (1997) documented that the below ground biomass (BGB) could be calculated by multiplying above-ground biomass with 0.26 as the root to shoot ratio. According to formula mentioned by

IPCC (2006) the below-ground biomass could be calculated using IPCC default value (above-ground biomass $\times$ 0.27) .

2.3 PARAMETER RECORDED FOR QUANTIFICATION OF CARBON SEQUESTRATION IN DIFFERENT LAND USE SYSTEMS

2.3.1 Biomass accumulation of different land use systems

2.3.1.1 Above ground biomass accumulation

Jarecki and Lal (2003) reviewed that the potential of agroforestry systems to store carbon was 0.25–1.58 Mg C ha⁻¹ yr⁻¹ in the soil and 0.98–6.7 Mg C ha⁻¹ yr⁻¹ in above-ground biomass.

NRCAF (2007) conducted a comparative study on biomass production from natural grassland and silvipastoral system and found that the rate of biomass carbon stored in silvipastoral system was 6.72 t C ha⁻¹ yr⁻¹, which was 2 times more than 3.14 t C ha⁻¹ yr⁻¹ from natural grasslands. Rai *et al.* (2009) studied the effect of introducing a silvipastoral system in a natural grassland in semi-arid Uttar Pradesh. There, the carbon storage was reported to be 1.89–3.45 t C ha⁻¹ in silvipasture and 3.94 t C ha⁻¹ in pure pasture.

Chavan and Rasal (2012) conducted biomass analysis in *Annona squamosa* and *Annona reticulata* tree species which was estimated by destructive methods followed by the ash content method. Carbon content in *Annona reticulata* and *Annona squamosa* was 83.1 kg C ha⁻¹ and 73.5 kg C ha⁻¹ respectively.

Chavan and Rasal (2012) reported that the standing above-ground biomass in *Mangifera indica* trees had 82.83 t ha⁻¹.

Pragasan and Karthick (2013) noticed that above ground biomass for the sites with *Eucalyptus* plantation and mixed species plantation 41.78 & 6.27 t ha⁻¹ respectively.

Singh *et al.* (2013) observed that *Z. mauritiana* + *P. cineraria* combination produced greater fruit, fodder and fuel wood and was less competitive to wheat crop. Utilizable biomass was 2.63 t ha⁻¹ from *C. myxa* (cursive) + *P. cineraria*, 2.21 t ha⁻¹ from *C. myxa* (cursive) + *C. mopane* and 2.18 t ha⁻¹ from *Z. mauritiana* + *P. cineraria* combinations.

2.3.1.2 Below-ground biomass accumulation

Schroth *et al.* (2002) reported that multi-strata systems had a below-ground biomass of (4.3 – 12.9) Mg ha⁻¹ and for monoculture (3.2 – 17.1) Mg ha⁻¹. Chavan and Rasal (2012) conducted an experiment on the standing below ground biomass stalks in *Mangifera indica* trees and found it to be 21.54 t ha⁻¹ for *Mangifera indica*.

Pragasan and Karthick (2013) recorded that the below-ground biomass for the sites with *Eucalyptus* plantation and mixed species plantation were 34.47 t ha⁻¹ & 5.17 t ha⁻¹ (approximately 15 years old) respectively.

2.3.1.3 Total biomass accumulation

Sharma *et al.* (2008) conducted a study in 20 years old plantations to investigate patches of four non-nitrogen fixing tree species viz *Gmelina arborea*, *Cleistanthus collinus*, *Lagerstroemia parviflora* and *Emblica officinalis*. Total biomass production was found to be the maximum (42.265 kg tree⁻¹) with *Gmelina arborea* and minimum (21.351 kg tree⁻¹) with *Emblica officinalis*. Kumar *et al.* (2011) estimated the total biomass production to be maximum at 5 x 4 m spacing. Biomass in different poplar parts decreased with increasing row spacing due to decreased number of trees. Venkatesh and Ram Newaj (2012) studied that the silvipastoral system in degraded land of Uttar Pradesh, India accumulated 18.91 t ha⁻¹ to

22.25 t ha⁻¹ biomass in natural pasture and 32.20 to 35.01 t ha⁻¹ biomass in established pasture. Kanime *et al.* (2013) reported a maximum total biomass of 94.8 Mg ha⁻¹ by 10-year-old *Dalbergia sissoo* monoculture plantation and minimum by an 8-year-old *Populus deltoides* block plantation (63.0 Mg ha⁻¹). Bohre *et al.* (2013) reported from Singrauli, M.P (India) that the total biomass accumulation rate were 279.89 t ha⁻¹ and 371.54 t ha⁻¹ for *Tectona grandis* and *Gmelina arborea*, respectively. Joshi *et al.* (2013) at Terai region of Central Himalaya revealed that total biomass of the tree layer by *Dalbergia sissoo* plantation (10year) was 29.51 t ha⁻¹ .

Pragasan and Karthick (2013) noticed that the total biomass for site with *Eucalyptus* plantation was greater (48.05 t ha⁻¹) than site with mixed species plantation (39.64 t ha⁻¹) .

2.3.2 Carbon sequestration under different land use systems

2.3.2.1 Above ground biomass carbon

Reyes *et al.* (1992) reported that total above-ground biomass carbon sequestration were (0.166 t) and (11.247 t) by guava and mango, respectively. Kumar *et al.* (1998a) revealed that *Phyllanthus emblica* sequestered 40.7 Mg ha⁻¹ carbon in its above ground shoot.

Brown and Schroeder (1999) suggested that the most softwood and hardwood forests had an above ground biomass in the range of 50–150 Mg C ha⁻¹ and 75–175 Mg ha⁻¹ respectively.

Jana *et al.* (2009) observed that the total above ground biomass carbon stock in *Shorea robusta* and *Albizia lebbek* (6 year old) were 5.22 t C ha⁻¹ and 6.26 t C ha⁻¹ in the forest stands. Prasad *et al.* (2010) reported that *Emblica officinalis* had carbon content of (39.16 %) in a total dry biomass of (32.40 kg tree⁻¹)(10 year old).

Wardah *et al.* (2011) showed that the above ground carbon stock biomass (tree, herbaceous, necromass and litter) in a simple agroforestry systems was 42.42 Mg C ha⁻¹ and in the complex agroforestry systems was 98.46 Mg C ha⁻¹.

The above ground biomass, standing leaf and wood litter were estimated to be 18.26-5.81, 0.49-0.36, 0.06- 0.08 t ha⁻¹ carbon respectively for (10 year-old) poplar plantation Odiwe *et al.* (2012).

Dube *et al.* (2012) studied the carbon sequestration potential in three predominant ecosystems. Among *Pinus ponderosa*-based silvopastoral systems (SPS), *pine* plantations (PPP) and natural pasture (PST), PPP and SPS total above ground tree carbon were 38.4 and 53.1 kg tree⁻¹ in case of PPP and SPS respectively.

2.3.2.2 Below ground biomass carbon

Chavan (2010) estimated the below ground carbon of different trees at Aurangabad which were as follows, *Ficus religiosa* - 0.641 t tree⁻¹, *Ficus bengalensis* - 0.57t tree⁻¹, *Mangifera indica* - 0.46 t tree⁻¹, *Delonix regia* - 0.31 t tree⁻¹, *Butea monosperma* - 0.31 t tree⁻¹, *Peltaforum pterocarpum* - 0.29 t tree⁻¹, *Azadirachta indica* - 0.26 t tree⁻¹, *Pongamia pinnata* - 0.23 t tree⁻¹ and *Hyophorbe amercaulismort* - 0.23 t tree⁻¹, respectively. However, Chavan and Rasal (2012) reported that the carbon sequestrated by *Mangifera indica* trees below ground were 11.63 t ha⁻¹

Wardah *et al.* (2011) showed that the below ground carbon stock in a simple agroforestry were 83.55 Mg C ha⁻¹ and in the complex agroforestry 110.93 Mg C ha⁻¹.

Dube *et al.* (2012) observed that the carbon sequestration potentials among three predominant ecosystems of *Pinus ponderosa*-

based silvopastoral systems (SPS), *pine* plantations (PPP) and natural pasture (PST), total below ground tree carbon were 21.3 and 23.4 kg tree⁻¹ for PPP and SPS respectively. Prasad *et al.* (2012) suggested that the below ground biomass carbon was about 12 t ha⁻¹ by eucalyptus and it was higher in farm forestry system.

2.3.2.3 Total biomass carbon

Singh (2005) at arid region of Rajasthan reported that the total carbon storage under *Emblica officinalis* + *Vigna radiate* agri-horti system was 12.7 -13.0 t ha⁻¹.

Chavan (2010) estimated that the total carbon sequestration in *Ficus religiosa* were 4.91 t tree⁻¹, *Ficus bengalensis* - 4.46 t tree⁻¹, *Mangifera indica* - 3.59 t tree⁻¹, *Delonix regia* - 2.44 t tree⁻¹, *Butea monosperma* - 2.41 t tree⁻¹, *Peltaforum pterocarpum* - 2.30 t tree⁻¹, *Azadirachta indica* - 2.08 t tree⁻¹, *Pongamia pinnata* - 1.80 t tree⁻¹ and *Hyophorbe amercaulismort* - 1.76 t tree⁻¹, respectively.

Kaul *et al.* (2010) observed that the total carbon storage ranged from 101 to 156 Mg C ha⁻¹, with the largest carbon stock in Sal forests (82 Mg C ha⁻¹ and minimum *Poplar* (8 Mg C ha⁻¹ yr⁻¹) and *Eucalyptus* (6 Mg C ha⁻¹ yr⁻¹) plantations followed by moderate growing *teak* forests (2 Mg C ha⁻¹yr⁻¹) and slow growing long rotation *Sal* forests (1 Mg C ha⁻¹ yr⁻¹).

Fang *et al.* (2010) reported that the total carbon stock reached 16.7 t C ha⁻¹ for the poplar with wheat–soybean cropping system and 18.9 t C ha⁻¹ for the poplar with wheat–corn cropping system.

Chauhan and Gera (2010) conducted study on the carbon sequestration potential of medicinal tree species, and found by

Terminalia arjuna (arjun) 137 t C which was followed by *Emblica officinalis* (amla) with 48 t C.

Wardah *et al.* (2011) showed that the total carbon stored in the simple agroforestry was 125.97 Mg C ha⁻¹ and in the complex agroforestry was 209.39 Mg C ha⁻¹.

Kakkar and Nagaraja (2011) conducted an experiment to evaluate the carbon storage potential by *Syzygium cumini*, *Gmelina arborea*, *Tectona grandis*, *Acacia auriculiformis*, *Dalbergia latifolia*, *Terminalia chebula* and *Hardwickia binnata* plantations. The results were 2.94, 19.28, 5.31, 21.30, 7.67, 7.70 and 5.35 (t ha⁻¹) respectively. *Acacia auriculiformis* followed by *Gmelina arborea* sequestered highest carbon.

Bohre *et al.* (2013) reported that the total carbon sequestration by *Tectona grandis* and *Gmelina arborea* were 139.91 t ha⁻¹ and 185.77 t ha⁻¹, respectively

Pragasam and Karthick (2013) reported that the total carbon stock sequestered by *Eucalyptus* plantation (EP) and mixed species plantation (MP) (approximately 15 years old) were 27.72 and 22.25 t ha⁻¹ respectively.

Rathore and Jasrai (2013) studied the average carbon stock of different tree species at dry semi-arid type of Gujarat & the results were mango (35.75 t), anola (43.57 t) and guava (4.23 t).

Pandya *et al.* (2013) conducted an experiment and found maximum carbon storage in *Tamarindus indica* (55.95 t C) followed by 44.8 t C for *Terminalia arjuna* and minimum in *Emblica officinalis* 1.77 t C.

2.3.2.4 Rate of carbon sequestration

Mandal *et al.* (2007) reported that rice mustard-sesame had significantly higher rate of carbon sequestration ($1.91 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$) than rice-fallow-rice ($0.28 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$) and rice-wheat-fallow ($0.27 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$). Jana *et al.* (2009) documented that the *Shorea robusta* and *Albizia lebbek* (6 years) had the annual rate of carbon sequestration of 8.97 t and $11.97 \text{ t C ha}^{-1}$ respectively.

Kaul *et al.* (2010) showed higher rate of carbon sequestration for poplar ($8 \text{ Mg ha}^{-1} \text{ yr}^{-1}$) than eucalyptus ($6 \text{ Mg ha}^{-1} \text{ yr}^{-1}$) and teak ($2 \text{ Mg ha}^{-1} \text{ yr}^{-1}$), respectively.

Brakas and Aune (2011) indicated that highest rate of carbon accumulation could be for mango (*Mangifera indica* L.) plantation ($17.9 \text{ Mg ha}^{-1} \text{ yr}^{-1}$) followed by banana (*Musa* spp.) + fruit trees ($13.6 \text{ Mg ha}^{-1} \text{ yr}^{-1}$), and ($<1 \text{ Mg ha}^{-1} \text{ yr}^{-1}$) rates of carbon accumulation for coconut (*Cocos nucifera* L.) plantations, coconut + banana, bush fallow, and grasslands.

Rizvi *et al.* (2011) reported that poplar-based system had carbon accumulation rate of about $11.9 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ under irrigated conditions of Indo-Gangetic plains and acacia hybrid-based system had $3.3 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ under high rainfall conditions.

Kanime *et al.* (2013) conducted an experiment and observed that the fruit trees had the highest sequestration rate of about ($1.43 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$) by *Mangifera indica* L.

Joshi *et al.* (2013) estimated that the rate of carbon sequestration by *Eucalyptus* hybrid (8 year) was $7.89 \text{ t ha}^{-1} \text{ yr}^{-1}$ and *Dalbergia sisoo* (10 year) was $6.47 \text{ t ha}^{-1} \text{ yr}^{-1}$.

2.3.2.5 Amount of CO₂ sequestration

Reyes *et al.* (1992) reported the total CO₂ sequestration of 0.610 t and 41.239 t by guava and mango, respectively.

Kraenzel *et al.* (2003) showed that the above ground CO₂ sequestration was 191.1 Mg CO₂ ha⁻¹ by *Tectona grandis* (20 year old) plantations.

Hairiah, (2009) referred that the atmospheric carbon dioxide (CO₂) captured by *Mangifera indica* was 206.84 t CO₂ ha⁻¹.

Chauhan and Gupta *et al.* (2011) conducted an experiment and reported that the annual average CO₂ assimilated by the biomass in the *Poplar-Wheat* based agroforestry system was higher (40.15 Mg ha⁻¹) against 20.9 Mg ha⁻¹ for agricultural system.

2.3.2.6 Rate of CO₂ sequestration

Prasad *et al.* (2010) reported from an experiment, that the rate of CO₂ sequestration was (4.65 Kg tree⁻¹yr⁻¹) by *Emblica officinalis* of different agroforestry trees (10 years old).

2.3.3 Carbon credit under different land use systems

Derwisch *et al.* (2009) found that carbon credits were worth about 460 US \$ for temporary CER and 560 US \$ for long-term CER, which contributed to 1% overall revenues under teak plantation (20 year old).

2.4.4 Soil Physico- chemical properties

2.4.4.1 Soil organic carbon (%)

Eswaran *et al.* (1993) observed that the global SOC pool contains 1500 Pg C and is two to three times greater than the amount of carbon stored in vegetation.

John (2004) reported a soil organic carbon of 0.72 to 0.97 % at a depth of 0-15 cm in wheat. Das *et al.* (2011) observed 0.45% soil organic carbon in soil (0–15 cm depth) on 6-year-old (*Emblica officinalis* Gaertn. cv. NA-7) orchard under rainfed calciorthent soil. While, Das *et al.* estimated that the maximum content of soil organic carbon for paddy was in 0-30 cm layer (0.82%). Gupta *et al.* (2009) at central Punjab of NW India observed an average SOC of 0.36% in sole crop and 0.66% in *poplar*-based agro-forestry plantation under agro-forestry soils.

Chandra *et al.* (2009) conducted an experiment and observed that soil organic carbon varied in three different systems i.e., forest, horticulture and agriculture. In forest system at 0-15 cm depth of soil it was found to be SOC 44.5 Mg C ha⁻¹ and in horticulture system 22.2 Mg C ha⁻¹ , in agriculture system 18.8 Mg C ha⁻¹. At 30 cm depth of soil, soil organic carbon in forest system was 79.6 Mg ha⁻¹ , in horticulture 37.5 Mg C ha⁻¹ and in agriculture system 33.1 Mg ha⁻¹.

Sudha and George (2011) observed that among the different cropping systems, *Coconut (Cocos nucifera)* + *Pineapple (Ananas comosus)* system maintained the highest SOC of 1.30%.

Koul and Panwar (2012) reported that the soil organic carbon ranged from 0.399% to 1.768 % in different agro-forestry systems but it was lower in paddy field.

Gupta *et al.* (2014) reported that amongst orchards, the maximum SOC stock was under *Citrus lemonum* (lemon) and the minimum under *Aegle marmelos* (bel). In agroforestry land uses, *A. excelsa*–*Gossypium* herbaceum (kapas) model contained the highest amount of SOC whereas *Cicer arietinum* (Chana) – *Acacia tortilis* (Israeli babool) stored minimum amount of SOC.

2.4.4.2 Bulk density (g cm^{-3})

Smith and Heath (2002) reported that the soil bulk density ranged from 0.77 to 0.84 g cm^{-3} . John (2004) reported a soil bulk density between 1.33 g cm^{-3} at 0-15 cm and 1.41 g cm^{-3} at 15-30 cm soil depth in wheat.

Sharma (2004) found that the bulk density ranged from 1.20 to 1.52 g cm^{-3} in wheat.

2.4.4.3 Soil organic carbon density (t ha^{-1})

Singh *et al.* (2011) observed that the C stock ranged from 8.5 to 15.2 t C ha^{-1} at the upper 40 cm soil layer.

They further reported that the SOC concentration was highest (101.8 Mg ha^{-1} in 0–30 cm, 227.97 Mg ha^{-1} in 0–100 cm) in temperate and lowest in subtropical climate (37 Mg ha^{-1} in 0–30 cm, 107.04 Mg ha^{-1} in 0–100 cm). SOC stocks were greater in natural ecosystems like forests and pastures (112.5 to 247.5 Mg ha^{-1}) than agriculture (63 to 120.4 Mg ha^{-1}). In temperate climate, SOC stock in agriculture (253.6 Mg ha^{-1}) on well formed terraces was little higher than forest (231.3 Mg ha^{-1}) on natural slope.

Srinivasarao *et al.* (2013) reported that the rate of depletion of soil organic carbon was 0.15 $\text{Mg C ha}^{-1}\text{yr}^{-1}$ in rice based system and

highest in groundnut–finger millet system ($0.92 \text{ Mg C ha}^{-1}\text{yr}^{-1}$) in semi-arid bioclimatic (Alfisols).

Gupta *et al.* (2009) recorded higher soil organic carbon $2.9\text{--}4.8 \text{ Mg ha}^{-1}$ under agroforestry systems than in sole crop.

Fonseca *et al.* (2011) reported the soil carbon accumulation of $1.1 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ by young secondary forests (4 to 20 years), while in the forest it was 180.4 Mg ha^{-1} (20 years).

Dube *et al.* (2012) observed that soil organic carbon stocks at (0–40) cm depth were 193.76 , 177.10 and $149.25 \text{ Mg ha}^{-1}$ in *Pinus ponderosa*-based silvopastoral systems (SPS), natural pasture (PST) and pine plantations (PPP) respectively.

Grace *et al.* (2012) reported that the carbon sequestration potential of rice–wheat systems of India was 44.1 Mt C under of no-tillage of 20 years. Implementing no-tillage practices in maize–wheat and cotton–wheat production systems would yield an additional 6.6 Mt C on indo-gangetic plains. Whereas, Makumba *et al.* (2007) at the Makoka (Malawi) reported that the amount of organic carbon would vary from 0.8 to 4.8 Mg C ha^{-1} by *Gliricidia*-maize and 0.4 to 1.0 Mg C ha^{-1} by sole-maize.

Kimaro (2009) recorded that soil organic carbon stocks (within 0–30 cm depth) under 5 year old rotational woodlots ($15.8\text{--}25.6 \text{ Mg C ha}^{-1}$) in Morogoro were higher than in soils that has been continuously cropping for the same time period (13 Mg ha^{-1}) and fallowed Miombo soils had $9\text{--}15 \text{ Mg C ha}^{-1}$.

2.5.5 Carbon sequestration of surface leaf litter under different land use systems

Ullah and Amin (2012) revealed a carbon stock of 4.21 t ha^{-1} in litter fall by the forest. Furthermore, Wardah *et al.* (2011) showed that

the total carbon stored in lower litter averaged 1.7 Mg C ha⁻¹ with a range of 1.62-1.77 Mg C ha⁻¹ by simple agroforestry, whereas an average of 2.29 Mg C ha⁻¹ with a range of 2.23 to 2.39 Mg C ha⁻¹ in complex agroforestry system. Moreover, Schelhaas *et al.* (2004) examined temperate grasslands and found 7.0 Mg C ha⁻¹ in *Tectona grandis* plantations. Similarly, Kraenzel *et al.* (2003) at Chiriqui found that the average carbon stock 3.4 Mg C ha⁻¹ in the herbaceous/litter layer, whereas average leaf litter found in the three *Tectona grandis* (3.6 Mg C ha⁻¹).

2.6.6 Economic analysis under different land use systems

Newaj and Rai (2005) observed a gross income of Rs 60,712 ha⁻¹ from anola at age of 13 years. Similarly the net income was positive in all the years except in first, third and six years when anola had no fruiting/or less fruiting. The B: C ratio (3:28) from the anola system (13 years) was quite effective which indicated that aonla based agroforestry system is a profitable enterprise in marginal lands under rainfed conditions.

Das *et al.* (2011) reported that the 6-year-old aonla (*Emblica officinalis* Gaertn. cv. NA-7) orchard under rainfed calciorthent soil, They assessed it in terms of economic analysis that means in terms of benefits: cost ratio, it revealed that 'aonla + turmeric' gave a higher value (6:29) followed by 'aonla + ginger' (3:44) and 'aonla + arbi' (3:20).

Rao (2014) reported that the B: C ratio (5:0, 3:21 and 2:28) in agri-horticulture systems, *mango* orchard and *guava* orchard under alternate land use systems in dryland, respectively.

Chandra (2014) observed the economic parameters of two intercrops *Amorphophallus paeonifolius* (Variety-Gajendra-1), *Dennst Nilolson* and *Curcuma longa* L. (Variety- Narendra haldi-1. The Benefit

Cost Ratio (BCR) was recorded 4:74 for Fruit tree + *C. longa* and 2:70 for fruit tree + *A. paeoniifolius* respectively while 2:78 and 1:52 for *C. longa* and *A. paeoniifolius* were computed with monocropping. The cultivation of *A. paeoniifolius* proved more remunerative and better intercrop than *C. longa*.



The present investigation “Evaluation of carbon sequestration potential under different land use systems” was carried out during *Kharif* and *Rabi* seasons of 2014-15 at Rajiv Gandhi South Campus, Barkachha, Mirzapur U.P.A detailed account of the materials used, experimental procedure and method adopted during the course of field investigation has been in this chapter.

3.1 EXPERIMENTAL SITE

The experiment was carried out at the agroforestry block of Agricultural Research Farm of Rajiv Gandhi South Campus, Barkachha , Mirzapur (BHU) which is situated the in South-East of Mirzapur in *Vindhyan* region at 25° 10’ latitude, 82° 37’ longitude and an altitude of 147 meters above mean sea level occupying over an area of more than 1000 ha of land.

3.2 CLIMATE AND WEATHER

Mirzapur falls in a belt of semi-arid to sub-humid climate. The normal period for the onset of monsoon in this region is the third week of June and it lasts up to the end of September or sometimes extends to the first week of October. Winter showers are often experienced in between the month of December to mid of February. However, March to May is generally dry. On an average, out of the total annual rainfall major fraction (75 %) is received from June to September. The winter months are cool whereas summers are hot and dry. The coldest and hottest months are January and May, respectively. The temperature begins to rise from the month of February and reaches its maximum in May.

3.3 WEATHER DURING EXPERIMENT

The meteorological data obtained from the meteorological observatory of Krishi Vigyan Kendra, Rajiv Gandhi South Campus of Banaras Hindu University, Varanasi are presented in fig. 3.1 and appendix I.

3.3.1 Rainfall (mm)

Total rainfall received during the crop growth period was 1049.34 mm. The maximum rainfall of 446.32 mm was recorded in August 2014 and minimum rainfall of 3.40 mm was recorded in February 2015.

3.3.2 Temperature (°C)

The monthly mean maximum and minimum temperature, during the period of experiment, ranges from 19.94°C to 36.75°C and 10.51°C to 27.34°C, respectively. The maximum temperature 36.75°C was recorded in the month of June, whereas the minimum temperature 10.51°C was observed in the month of December.

3.3.3 Relative humidity (%)

The monthly maximum relative humidity of 90.20 to 94.68% in and monthly minimum relative humidity 55.36 to 72.81% in during the period of experimentation.

3.4 LAND USE

Rainfed agriculture is the tradition farming practice followed in the region. Variety of crops like agricultural, horticultural, medicinal and aromatic plants are grown. Barkachha soil (red lateritic) comes under rainfed and invariably poor fertility status. This region comes under agro-climatic zone III A (semi-arid eastern plain zone). Land use and other characteristics are shown in Table 3.1.

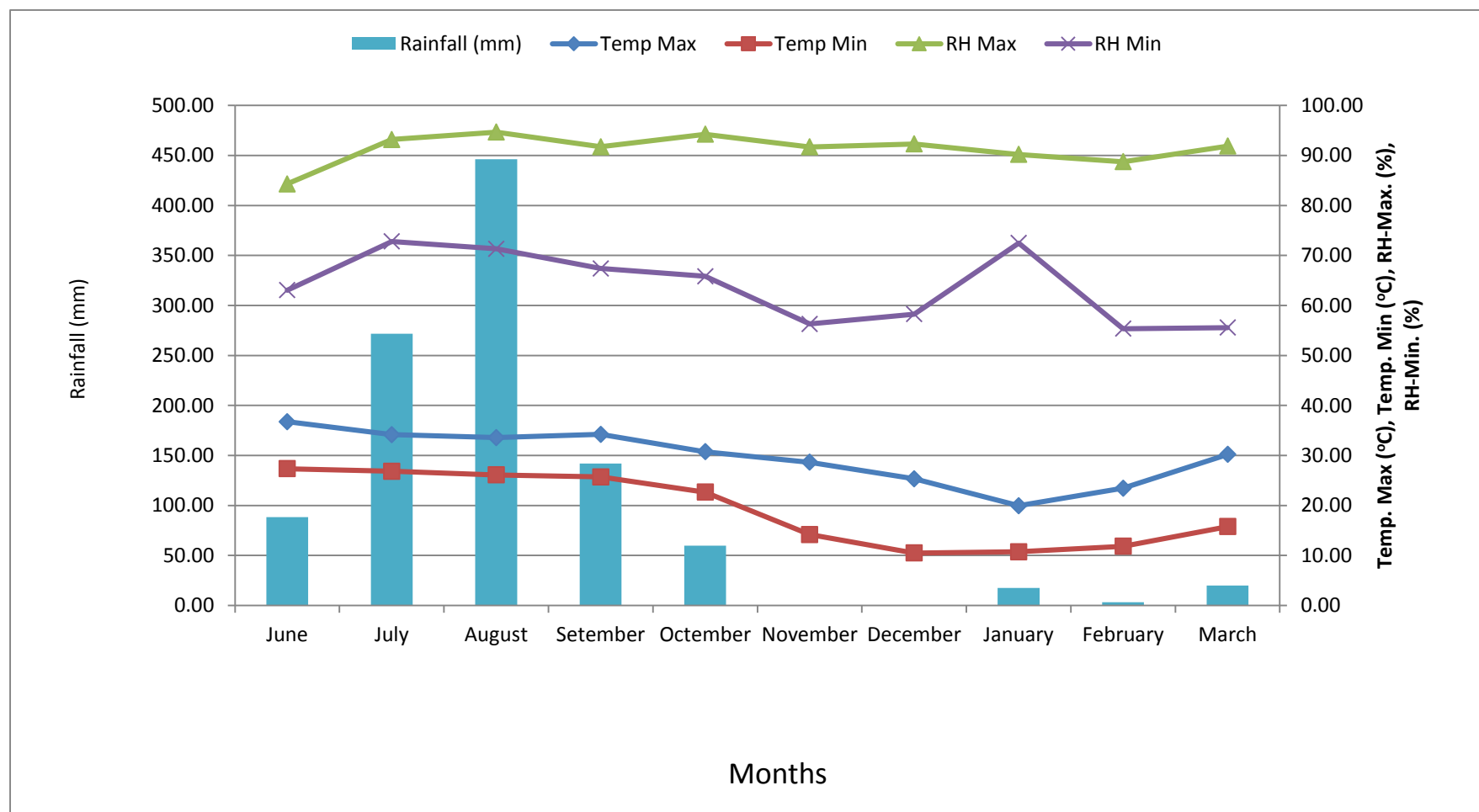
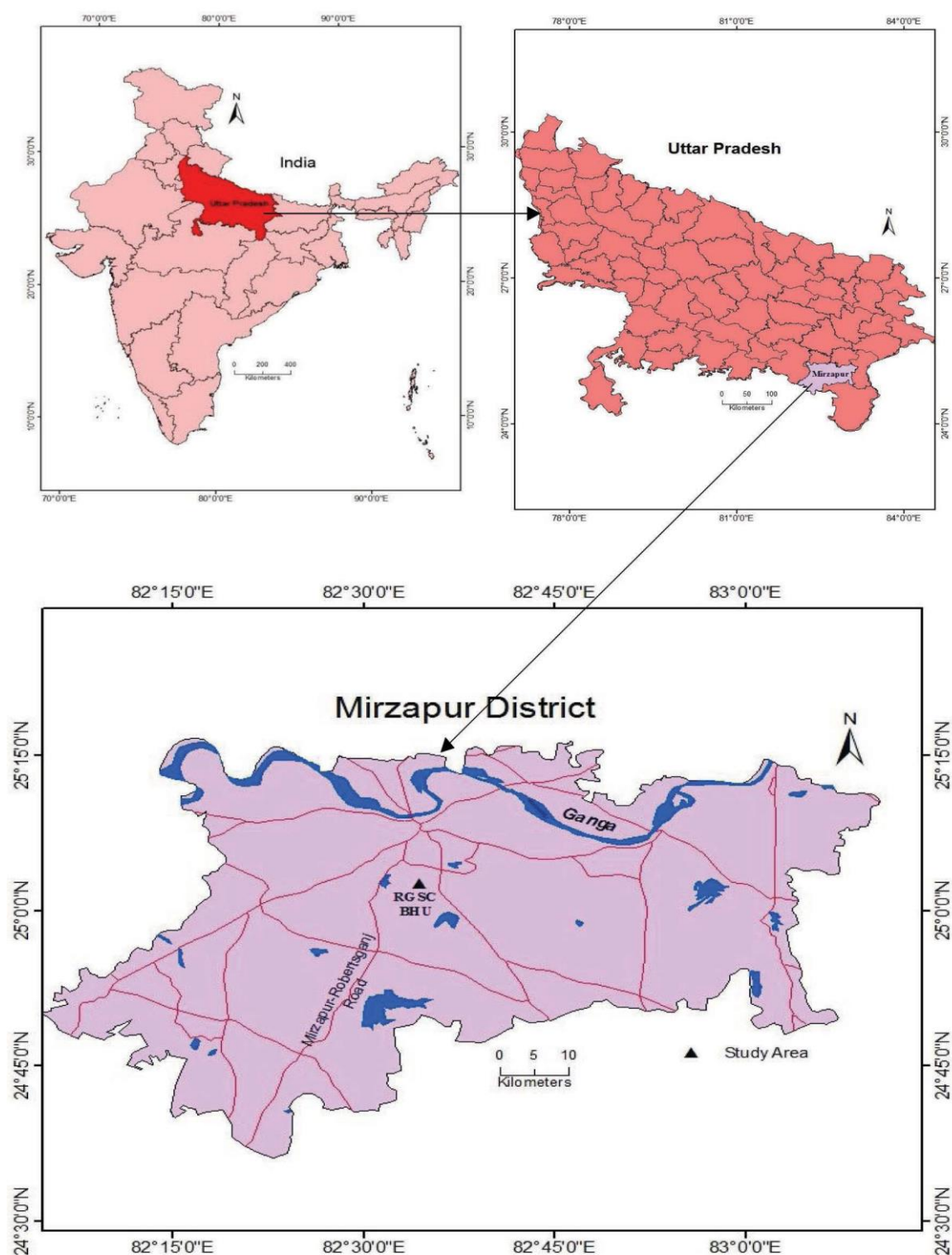


Fig. 3.1. Mean month-wise meteorological data during experiment, 2014-15

Table 3.1: Land use and other agricultural characteristics of the study area – Rajiv Gandhi South Campus (2014-2015)

S. No.	Agricultural parameters	Area (ha)
1	Geographical area (GA)	2763 acre
2	Forest area	500 acre
3	Land not available for cultivation – non-agricultural uses	1880 acre
4	a)Current fallows	900 acre
	b)Other fallows	450 acre
5	Pasture land	200 acre
6	Net cropped area (NCA)	375 acre
7	Area sown more than once	78 acre
8	Total cropped area	450 acre
9	Intensity of cropping	120%
10	Cultivable waste land	300 acre
11	Cultivated area	450 acre
12	Barren land	1888 acre
13	Land under misc. tree crops and groves	515 acre
14	Net irrigated area	100 acre
15	Gross irrigated area	175 acre
16	Rainfed area	275 acre

Fig. 3.2: Location of Rajiv Gandhi South Campus



3.5 SOIL

The soil, as a medium of plant support and growth, is bound to affect substantially the rate of growth and development and eventually the final and economic yield through its biotic and abiotic activities and geo-physico-chemical properties.

Soil samples were collected at 0-15, and 15-30 cm depths. Samples of exactly 100 cm cubic were taken and transferred to pre-weighed sampling bags. Wet weights of soils were determined in the field with 0.1 gram precision. Subsequently, samples were transported to the laboratory and oven dried (70⁰C) until constant weight to determine moisture content. Samples from each of the two depths were well-mixed per sampling plot and prepared for carbon measurement by removing stones and plant residue > 2mm. The soil organic carbon was calculated as per formula suggested by Pearson *et al.*(2007)

$$SOC = p \times d \times \%c$$

where,

SOC= Soil organic carbon stock per unit area [t ha⁻¹],

p = Soil bulk density [g cm⁻³],

d = The total depth at which the sample was taken [cm], and

$\%C$ = Carbon concentration (%).

Table3.2 Physico-chemical properties the soil of experimental.

Soil properties	Value	Method employed
a. Physical		
Bulk density ((mg/m ³)	1.43	Core sampler method Black <i>et al.</i> (1965)
b. Chemical		
Organic carbon (%)	0.35	Walkley and Black rapid titration method (Piper, 1966)

3.6 EXPERIMENTAL DESIGN AND LAYOUT

Two experiment were conducted under these programme.

- 1) For estimation of the above ground biomass and associated carbon sequestration the experiment was conducted in a Randomized Complete Block Design with 11 treatments and 3 replications. The details if treatments are as follows-

Table3.3: Details of treatments (experiment – 1)

Treatments	Symbol
Land use systems (S)	
Pure guava orchard	: T ₁
Pure custard apple orchard	: T ₂
Pure karonda orchard	: T ₃
Pure amla orchard	: T ₄
Pure bael orchard	: T ₅
Agriculture(pearl millet + lentil)	: T ₆
Guava based agri-horti system (guava + pearl millet /guava+ lentil)	: T ₇
Custard apple based agri-horti system (custard apple + pearl millet/ custard apple+ lentil)	: T ₈
Karonda based horti-pasture system (karonda + grasses /karonda+grasses)	: T ₉
Amla based agri-horti system (amlam + pearl millet /amlam+ lentil)	: T ₁₀
Bael based agri-horti system (bael + pearl millet /bael+lentil)	: T ₁₁

- 2) For estimation of the below ground biomass the second experiment was conducted. These was a factorial experiment laid out in Randomized Complete Block Design with 2 factors and 3 replications. The details of factors and treatment combination given below-

Table3.4: Details of treatments (experiment -2)

Treatments	Symbol
Land use systems (S)	
Pure guava orchard	: T ₁
Pure custard apple orchard	: T ₂
Pure karonda orchard	: T ₃
Pure amla orchard	: T ₄
Pure bael orchard	: T ₅
Agriculture(pearl millet + lentil)	: T ₆
Guava based agri-horti system (guava + pearl millet /guava+ lentil)	: T ₇
Custard apple based agri-horti system (custard apple + pearl millet/ custard apple+ lentil)	: T ₈
Karonda based horti-pasture system (karonda + grasses /karonda+grasses)	: T ₉
Amla based agri-horti system (amla + pearl millet /amla+ lentil)	: T ₁₀
Bael based agri-horti system (bael + pearl millet /bael+lentil)	: T ₁₁
Soil Depth (cm)	
0-15	D ₁
15-30	D ₂

Table3.5: Details of treatment combinations

SYSTEM	DEPTH	
	D ₁	D ₂
S ₁	D ₁ S ₁	D ₂ S ₁
S ₂	D ₁ S ₂	D ₂ S ₂
S ₃	D ₁ S ₃	D ₂ S ₃
S ₄	D ₁ S ₄	D ₂ S ₄
S ₅	D ₁ S ₅	D ₂ S ₅
S ₆	D ₁ S ₆	D ₂ S ₆
S ₇	D ₁ S ₇	D ₂ S ₇
S ₈	D ₁ S ₈	D ₂ S ₈
S ₉	D ₁ S ₉	D ₂ S ₉
S ₁₀	D ₁ S ₁₀	D ₂ S ₁₀
S ₁₁	D ₁ S ₁₁	D ₂ S ₁₁

Table 3.6: Details of layout (Experiment 1)

Design	: Randomized Complete Block design
Treatments	: 11
Replications	: 03
Total number of plots	: 33
Guava plot size	: 50x10 m ²
Castard apple plot size	: 50x10 m ²
Karonda plot size	: 50x10 m ²
Amla plot size	: 50x10 m ²
Bael plot size	: 50x10 m ²
Annual crops	: 1x1 m ²
Planting distance	
Guava	: 7x7 m ²
Castard apple	: 5x5 m ²
Karonda	: 3x3 m ²
Amla orchard	: 7x7 m ²
Bael	: 7x7 m ²
Pearl millet – Lentil	: 40 x 10 cm - 30 x 10 cm

Table 3.7: Details of layout (Experiment 2)

Design	:	Factorial experiment in a Randomized Complete Block design
Treatment combinations	:	22
Replications	:	03
Total number of plots	:	66
<i>Guava</i> plot size	:	50x10 m ²
Castard apple plot size	:	50x10 m ²
<i>Karonda</i> plot size	:	50x10 m ²
Amla plot size	:	50x10 m ²
<i>Bael</i> plot size	:	50x10 m ²
Annual crops	:	1x1 m ²
Planting distance		
Guava	:	7x7 m ²
Castard apple	:	5x5 m ²
Karonda	:	3x3 m ²
<i>Amla</i> orchard	:	7x7 m ²
Bael	:	7x7 m ²
Pearl millet – Lentil	:	40 x 10 cm - 30 x 10 cm

Table3.8: Structures and composition of prevalent under different land use systems at R.G.S.C, Barkachha, Mirzapur.

Major Systems		System type	Spacing		Age of woody perennial(Yrs)
			Woody perennials	Intercrops	
Pure Orchard(PH)	1	Pure guava orchard	7x7 m ²		8
Pure Orchard(PH)	2	Pure custard apple orchard	5x5 m ²		8
Pure Orchard(PH)	3	Pure karonda orchard	3x3 m ²		8
Pure Orchard(PH)	4	Pure amla orchard	7x7 m ²		8
Pure Orchard(PH)	5	Pure bael orchard	7x7 m ²		8
Pure agriculture	6	Agriculture(pearl millet + lentil)		40 x 10 cm- 30 x 10 cm	8
Agri- horticulture system (AHS)	7	Guava based agri-horti system (guava + pearl millet /guava+ lentil)	7x7 m ²	40 x 10 cm- 30 x 10 cm	8
Agri- horticulture system (AHS)	8	Custard apple based agri-horti system (custard apple + pearl millet/ custard apple+ lentil)	5x5 m ²	40 x 10 cm - 30 x 10 cm	8
Horti – pasture system(HP)	9	Karonda based horti-pasture system (karonda + grasses /karonda+grasses)	3x3 m ²	1x1m ²	8
Agri- horticulture system (AHS)	10	Amla based agri-horti system (amlam + pearl millet /amlam+ lentil)	7x7 m ²	40 x 10 cm - 30 x 10 cm	8
Agri- horticulture system (AHS)	11	Bael based agri-horti system (bael + pearl millet /bael+lentil)	7x7 m ²	40 x 10 cm - 30 x 10 cm	8

3.7 DETAILS OF DIFFERENT LAND USE SYSTEMS

1. Pure guava orchard

Guava (*Psidium guajava*) a tropical and subtropical semi-dwarf fruit tree having 2.3–3.4 m tall, with vigorous with branching having flat crown. Leaves were large - 12.8-13.2 cm long and 6.8 cm width, ovate to oblong in shape. Fruits were roundish ovate in shape with an average fruit weight of 95.8–145.0 gram. The guava tree was planted at a spacing of 7x7m².

2. Pure custard apple orchard

Custard apple (*Annona squanmosa*) is a small, well ranched tree or shrub from the family *Annonaceae* that bears edible fruits call sugar apples. It tolerates a tropical lowland climate. It is a small, semi deciduous, much branched shrub or small tree, 3 meter to 8 meters tall. Leaves are thin simple, alternate, occur singly, fruit is pendulous on a thickened stalk. The custard tree was planted with a spacing of 5x5m².

3. *Pure* karonda orchard

Carissa carandas is a species of flowering shrub. It produces berry-sized fruits that are commonly used as a condiment in Indian pickles and spices. It is a hardy, drought-tolerant plant that thrives well in a wide range of soils. Leaves - opposite, obovte to oblong, cuneate base, obtuse apex, entire margin. Trunk - simple spines at alternate nodes; milky latex. Flowers - white or pink, in 3's, in axillary and terminal clusters. Fruits - reddish purple berries. The karonda tree was planted at a spacing of 3x3m².

4. Pure amla orchard

Phyllanthus emblica (syn. *Emblica officinalis*), the Indian gooseberry, or dhatrik (in maithili) or amla from sanskrit amalika, is a deciduous tree belonging to the family Phyllanthaceae. It is known for its edible fruit of the same name. The tree is small to medium in size, reaching 8 to 18 m in height, with a crooked trunk and spreading branches. The branchlets are glabrous or finely pubescent, 10–20 cm long, usually deciduous; the leaves are simple, sub sessile and closely set along branch lets, light green, resembling pinnate leaves. The flowers are greenish-yellow. The fruit is nearly spherical, light greenish yellow, quite smooth and hard on appearance, with six vertical stripes or furrows. Amla trees are usually planted in a square system at a spacing of $7 \times 7 \text{ m}^2$ apart.

5. Pure bael orchard

Bael (*Aegle marmelos*) is the only member of the monotypic genus *Aegle*. It is a mid-sized, slender, aromatic, armed, gum-bearing tree growing up to 18 meters tall. It has a leaf with three leaflets. The bael fruit has a smooth, woody shell with a green, gray, or yellow peel. Bael trees are usually planted in a square system, at a spacing of $7 \times 7 \text{ m}^2$ apart.

6. Guava based agri- horti system

In this system, agricultural crops were grown in combination with guava trees. Agricultural crops viz., lentil, pearl millet, til, urd bean and mustard were grown in between the alleys of guava plantation, where guava trees were planted at a spacing of $7 \times 7 \text{ m}^2$.

7. Custard apple based agri-horti system

In this system, agricultural crops were grown in combination with custard apple trees. Agricultural crops viz., mungbean, bajra,

lentil and gram were grown in between the alleys of custard apple plantation, where mango trees were planted at a spacing of 5x5 m²

8. Karonda based horti-pasture system

In this system, agricultural crops and grasses were grown in combination with karonda trees. Agricultural crops *viz.*, grasses, til, mung bean and mustard were grown in between the alleys of karonda plantation, where karonda trees were planted with a spacing of 3x3 m²

9. Amla based agri-horti system

In this system, agricultural crops were grown in combination with amla trees. Agricultural crops *viz.*, lentil, pearl millet, til, mung bean and mustard were grown in between the alleys of amla plantation, which were planted at a spacing of 7x7 m²

10. Bael based agri-horti system

In this system, agricultural crops were grown in combination with bael trees. Agricultural crops *viz.*, lentil, pearl millet, til, mungbean and mustard were grown in between the alleys of bael plantation, which were planted at a spacing of 7x7m²

11. Annual crop (both rabi and kharif)

An annual plant is a plant surviving just for one growing season. Most of the annual crops like mung bean lentil, rice, maize, sorghum and pearl millet completed their life cycles during kharif season, while wheat, barley, gram, mustard and lentil completed during rabi season with huge potential to store carbon in soil during their growing period. Many desert annuals *viz.* lentil, pearl millet, moth bean and sesamum are ephemerals because their seed-to-seed

life cycle completes only in a few weeks. Annual crops was estimated using 1x1 m² quadrates.

3.8 OBSERVATIONS RECORDED

3.8.1 Above ground biomass

3.8.1.1 Tree components

3.8.1.2 Stem biomass

To estimate biomass all the tree falling in the plot (50 x 10 m²) were enumerated. The diameter of trunk at breast height (dbh) was measured with caliper and height with Ravi's multi meter. Where volume equation was not available for the concerned species, form factor was calculated using Spiegel Relaskope to find out the tree volume as per the formula of Pressler's (1865) and Bitlerlich (1984)

$$f = \frac{2h_1}{3h}$$

where,

f = form factor

h₁ = height at which diameter is half of dbh

h = total height

Volume was calculated by Pressler's formula (1865)

$$V = f \times h \times g$$

where,

V = volume

f = form factor

h = total height

g = basal area = πr^2 or $\pi (dbh/2)^2$

where,

$r =$ radius

DBH = diameter at breast height

Specific gravity

Specific gravity was determined from the available literature. Where, the specific gravity values was not available in that case the stem cores were taken to find out specific gravity which was used to determine the biomass of the stem using maximum moisture method (Smith, 1954).

$$Gf = \frac{1}{\frac{Mn - Mo + 1}{Mo + Gso}}$$

where,

Gf = Specific gravity based on gross volume

Mn = Weight of saturated volume sample

Mo = Weight of oven- dried sample

Gso = Average density of wood substances equal to 1.53

Thus the weight of wood was estimated using the formula i.e. mass per unit volume

Mass = Average specific gravity of stem wood $\times$ volume

The biomass for *bael* and *amla* plantation in agroforestry system was estimated by using the regression equation given by Brown *et al.*, (1997).

$$Y = \exp\{-1.996 + 2.32 \times \ln(D)\}$$

where,

Y = Above ground biomass (kg)

D = Diameter at breast height

3.8.1.3 Branch biomass

Total numbers of branches irrespective of size was counted on each of the sample tree and categorized on the basis of basal diameter into three groups, *viz.*, < 6cm, 6-10cm, and >10 cm. Fresh weight of two sampled branches from each group was recorded separately. The formula (Chidumaya 1990) used to determine the dry weight of branches was as follows.

$$Bdwi = \frac{Btwi}{1+Mcbdi}$$

where,

Btwi = Oven dry weight of branch

Bdwi = Fresh/green weight of branches

Mcbdi = Moisture content of branch on dry weight basis

Total branch biomass (Fresh/dry) per sample tree was determined by:

$$Bbt = n1bw1 + n2bw2 + n3bw3 \sum nibwi$$

where,

BBt = Branch biomass (fresh/dry) per tree

Ni = Number of branches in the ith branch group

Bwi = Average weight of branch of ith group

I = 1, 2, 3, ----- refers to branch group

3.8.1.4 Leaf biomass

Leaves from the branches which were removed, were weighed and oven dried separately to a constant weight at $80 \pm 5^\circ\text{C}$ (Chidumaya, 1990). Leaf biomass of the forest tree species was estimated using the table given by Jenkins *et al.* (2003). The leaf biomass of each fruit tree on the other was calculated during the leaf fall (December-January). The fallen leaves under each tree were collected and dried to a constant weight in oven. Leaf carbon was converted into carbon by multiplying with a factor of 0.5.

3.8.1.5 Tree biomass

The total tree biomass was the sum of stem biomass, branch biomass and leaf biomass. The tree biomass was converted into carbon fraction by a factor of 0.5 (IPCC, 2006).

3.8.1.6 Fruit tree biomass

For estimation of fruit tree biomass, diameter-dry biomass based equations were developed. For this purpose, experimenter visited orchard field from time to time, when orchards were uprooted during winter. For each fruit tree crop, around 20 trees were selected. Each selected tree was then divided into secondary branches and main stem. The diameter of basal portion (with tree caliper) and fresh weight of each branch were determined in field with the help of balance. Dry weight of branches was estimated using the following equation (Chidumaya 1990).

$$\text{Bdwi} = \frac{\text{Bdwi}}{1 + \text{Mcbdi}}$$

where,

$$\text{Btwi} = \text{Oven dry weight of branch}$$

Bdwi = Fresh / green weight of branches

Mcbdi = Moisture content of branch on dry weight basis

After estimating the dry biomass of the each secondary branch, non-linear regression equation between diameter and dry biomass of the branches were developed. This regression equation was used to estimate the dry weight of secondary branches of the sample trees from the sample plot (Chidumaya 1990) .

Dry weight of the sample tree

= biomass of the main stem log + cumulative weight of all the secondary branches

Biomass of the main stem log was determined as below:

The volume of the main stem was calculated by the following formula:

$$\text{Volume of the main stem} = \frac{S_1 + S_2}{2} \times l$$

Smalian's formula (Khanna and Chaturvedi 1986)

where,

S_1 = Basal area of the lower portion

S_2 = Basal area of the upper portion

l = Length of the main stem

Biomass of the main stem of the sample tree

= volume of the main stem $\times$ specific gravity

Biomass of the sample tree

= biomass of the main stem

+ sum biomass of all the secondray branch

3.8.1.7 Fruit tree root biomass

In fruit trees, the trees uprooted by the farmers during their orchard replacement time, were used to develop the diameter-biomass equations on dry biomass and the same trees were used for the estimation of the fruit tree root biomass (Chidumaya 1990). On the basis of root and shoot biomass, shoot-root ratio was worked out.

3.8.1.8 Crop component

3.8.1.9 Crop biomass

Five plots of 1 x 1 m² were used for estimation of crop biomass. All the crops biomass occurring within the borders of the quadrates were cut at ground level and collected samples were weighed, sub sampled and oven dried at 65 ± 5°C till constant weight. The crop biomass was converted into carbon by multiplying it with a factor of 0.5 (IPCC, 2006).

3.8.1.10 Surface litter

Surface litters were collected in five quadrates of 1 x 1 m². Samples will be weighed, sub-sampled and oven dried at 65 ± 5°C to a constant weight ground. Surface litter corrected dry will assumed to contain 45% of carbon.

3.8.2 Below ground biomass

Below ground biomass of trees was calculated by using the guidelines of IPCC (1996) and Cairns *et al.* (1997). Below ground biomass of tree and crops will be calculated by multiplying above ground biomass of tree and crops with a factor of root: shoot ratio of particular crop.

$$\text{Below ground biomass} = \text{Above ground biomass} \times \text{Root: Shoot ratio}$$

3.8.3 C and CO₂ estimation

3.8.3.1 Carbon stock

Carbon stock was estimated as per the formula mentioned by IPCC (2006)

$$\text{Carbon stock} = \text{Biomass} \times 0.5$$

3.8.3.2 CO₂ estimation

CO₂ was estimated as per the formula suggested by Pearson *et al.* (2007)

$$\text{CO}_2 \text{ sequestered} = \text{Biomass carbon stock} \times 3.67$$

3.8.3.3 Carbon credits

One ton of net sequestered or mitigated carbon dioxide in the form of plant biomass is equal to one carbon credit (IPCC, 2007). Therefore, total carbon credit in a land use system was calculated from CO₂-eq values of retained biomass in respective system. The eligible carbon credits were calculated from the net sequestered or mitigated carbon dioxide in the form of tree or crop biomass only.

3.8.4 Economic yield

3.8.4.1 Biological yield

Biological productivity was calculated considering the utilizable biomass of each functional unit of the system type.

3.8.4.2 Economic productivity

The present utilizable biomass from each functional unit in a system was taken for estimating the total returns from the system whereas, the total investment incurred on production, land value of

the system and cultural management practices was taken into account to estimate the net returns.

3.9 ECONOMICS

3.9.1 Gross return (Rs/ha)

The biomass and fruit of different land use systems was converted into gross return in rupees per hectare on the basis of current price of the produce.

3.9.2 Net return (Rs/ha)

The net return was worked out by using following formula:

$$\text{Net return (Rs./ha)} = \text{Gross return (Rs./ha)} - \text{cost of cultivation(Rs./ha)}$$

3.9.3 Carbon credits

One ton of net sequestered or mitigated carbon dioxide in the form of plant biomass is equal to one carbon credit (IPCC 2007). Therefore, total carbon credit in a land use system was calculated from CO₂-equivalent values of retained biomass in respective system. The eligible carbon credits were calculated from the net sequestered or mitigated carbon dioxide in the form of tree or crop biomass only.

3.9.4 Benefit: cost ratio (BCR)

Benefit: cost ratio of various treatments was worked with help of following formula.

$$\text{Benefit: cost ratio} = \frac{\text{Net return (Rs/ha)}}{\text{Cost of cultivation (Rs/ha)}}$$

3.10 STATISTICAL ANALYSIS

Data collected on biomass and carbon of the experimental crop were tabulated and statistically analyzed as per the standard analysis of variance to draw valid conclusions (Gomez and Gomez, 1984). The treatment differences were tested by 'F' test of significance on the basis of null hypothesis. Critical differences were worked out at 5 per cent level of probability where 'F' test was significant. The mean biomass, carbon, soil organic carbon, bulk density of different land use systems were collected and analyzed.

If the variance ratio (F test) was found significant at 5% level of significance, the standard error of mean ($SEm\pm$) and critical differences (CD) were calculated for further comparison by using following formula.

$$SEm\pm = \sqrt{EMS/r}$$

$$C.D. = S.E.m\pm \times \sqrt{2} \times t_{error d.f. \text{ at } 5\%}$$

$$C.V. (\%) = \sqrt{EMS/GM} \times 100$$

where,

DF = Degree of freedom,

C.D. = Critical difference,

S.S. = Sum of square,

M.S.S.= Mean sum of square

EMS = Error mean square,

C.V. = Coefficient of variance,

S.E.m $\pm$ = Standard error of mean

Table 3.9: ANOVA Table (experiment no. 1)

Source of variation	DF	SS	MSS	F cal	F tab (5%)
Replication (R)	2				
System (S)	10				
Error	20				
Total	32				

Table3.10: ANOVA Table (experiment no.2)

Source of variation	DF	SS	MSS	F cal	F tab (5%)
Replication (R)	2				
System (S)	10				
Depth (D)	1				
Interaction (SxD)	10				
Error	42				
Total	65				



The present investigation entitled “Evaluation of carbon sequestration potential under different land usesystems” was carried out through 2 experiment. The first one was Randomized Complete Block Design (RCBD) with 11 treatments (land use system) and 3 replications, while the second trial was a Factorial experiment laid out in a Randomized Complete block Design with 2 factors (soil depth) and 3 replications. The results showing the effect of biomass accumulation, carbon sequestration potential, rate of C and CO₂sequestration, carbon credits, surface leaf litter, soil organic carbon, bulk density, total organic carbon pool and economic analysis under different land use systems are presented in this chapter under the following headings.

4.1 *Effect of different land use systems on biomass accumulation*

4.1.1 Aboveground biomassaccumulation (t ha⁻¹)

4.1.2 Belowground biomass accumulation (t ha⁻¹)

4.1.3 Totalbiomass accumulation (t ha⁻¹)

4.1.4 Rate of biomass accumulation (t ha⁻¹ yr⁻¹)

4.2 *Effect of different land usesystems on potential of carbon sequestration*

4.2.1 Above ground biomass carbon (t ha⁻¹)

4.2.2 Below ground biomass carbon (t ha⁻¹)

4.2.3 Total biomass carbon (t ha⁻¹)

- 4.2.4 Rate of carbon sequestration ($\text{t ha}^{-1} \text{ yr}^{-1}$)
- 4.2.5 Amount of CO_2 sequestration (t ha^{-1} of the total age – 8 yrs)
- 4.2.6 Rate of CO_2 sequestration ($\text{t ha}^{-1} \text{ yr}^{-1}$)
- 4.3 *Carbon credits under different land use systems* ($\text{Rs. ha}^{-1} \text{ yr}^{-1}$)
- 4.4 *Effect on soil physico- chemical properties under different land use systems*
 - 4.4.1 Soil organic carbon (%)
 - 4.4.2 Bulk density (g cm^{-3})
 - 4.4.3 Soil organic carbon density (t ha^{-1})
- 4.5 *Effect of surface leaf litter under different land use systems*
 - 4.5.1 Fresh weight of surface leaf litter (t ha^{-1})
 - 4.5.2 Dry weight of surface leaf litter (t ha^{-1})
 - 4.5.3 Carbon stock of surface leaf litter (t ha^{-1})
- 4.6 *Economic analysis under different land use systems*
 - 4.6.1 Gross return (Rs. ha^{-1})
 - 4.6.2 Cost of cultivation (Rs. ha^{-1})
 - 4.6.3 Net returns (Rs. ha^{-1})
 - 4.6.4 Total benefit (net profit + carbon credit) ($\text{Rs ha}^{-1} \text{ yr}^{-1}$)
 - 4.6.5 B: C ratio

4.1 EFFECT DIFFERENT LAND USE SYSTEMS ON BIOMASS ACCUMULATION

4.1.1 Above ground biomass (Table 4.1)

Land usesystems. Perusal of data indicated that bael + pearl millet/bael+ lentil (T₁₁) agri-horti system was having significantly higher above ground biomass (35 tha⁻¹) as compared to other treatments. Furthermore, statistically similar above ground biomass was observed under amla+ pearl millet/amla+ lentil(T₁₀) and custard apple + pearl millet /custard apple + lentil(T₈) and this was followed by guava + pearl millet / guava + lentil (T₇), whereas, pure orchard karonda (T₃) recorded the lowest above ground biomass (8 t ha⁻¹) among all the treatments .

4.1.2 Belowground biomass (Table 4.1)

Land use systems. Perusal of data indicated that among the agroforestry systems with combinations of bael + pearl millet / beal + lentil produced the highest below ground biomass (9.10 t ha⁻¹), while the lowest was found in (T₉) i.e. karonda+ grasses / karonda + grasses (3.12 t ha⁻¹). Further among the pure orchards beal (T₅) showed the highest below ground biomass (4.68 t ha⁻¹) while the lowest was found with pure karonda(T₃) (2.08 t ha⁻¹).

4.1.3 Total biomass (Table 4.1)

*Land use systems.*Critical appraisal of the data revealed that bael + pearl millet/bael + lentil (T₁₁) agri-horti system produced significantly higher total biomass (44.10 t ha⁻¹) as compared to other treatments. Furthermore, statistically at par total biomass was observed under amla+ pearl millet /amla+ lentil (T₁₀) and custard apple + pearl millet /custard apple + lentil agri-horti system (T₈) and this was followed by guava + pearl millet / guava + lentil (T₇), whereas, pure orchard karonda (T₃) recorded the lowest above ground biomass (10.08 t ha⁻¹) among all the treatments.

4.1.4 Rate of biomass accumulation (Table 4.1)

Land use systems. Perusal of data indicated that among the agroforestry systems, combinations of bael + pearl millet / beal + lentil showed the fastest rate of biomass accumulation (5.51 t ha^{-1}), while the slowest was found in (T₉) i.e. karonda+ grasses / karonda + grasses (1.89 t ha^{-1}). Further among the pure orchards beal (T₅) showed the highest rate of biomass accumulation (2.84 t ha^{-1}) and the lowest was found with pure karonda (T₃) (1.26 t ha^{-1}).

Table 4.1 Effect of different land use systems on amount and rate of biomass accumulation at RGSC, BHU, Barkachha, Mirzapur.

Treatments	Biomass accumulation			
	Above ground (t ha^{-1})	Below ground (t ha^{-1})	Total (t ha^{-1})	Rate ($\text{t ha}^{-1} \text{ yr}^{-1}$)
<i>Land use systems (S)</i>				
T ₁ - Pure guava orchard	8.28	2.18	10.46	1.31
T ₂ - Pure custard apple orchard	13.00	3.38	16.38	2.05
T ₃ - Pure karonda orchard	8.00	2.08	10.08	1.26
T ₄ - Pure amla orchard	14.10	3.67	17.77	2.22
T ₅ - Pure bael orchard	18.00	4.68	22.68	2.84
T ₆ - Pure agriculture(pearl millet - lentil)	17.00	4.42	21.42	2.68
T ₇ - Guava + pearl millet/guava +lentil	25.00	6.50	31.5	3.94
T ₈ - Custard apple + pearl millet /custard apple+Lentil	30.00	8.13	38.13	4.77
T ₉ - Karonda + grasses /karonda+ grasses	12.00	3.12	15.12	1.89
T ₁₀ - Amla + pearl millet /amlal+lentil	31.00	8.07	39.07	4.88
T ₁₁ - Bael + pearl millet /bael+lentil	35.00	9.10	44.1	5.51
SEm±	0.88	0.62	0.47	0.37
CD (P=0.05)	2.59	1.84	1.38	1.10

4.2 EFFECT OF DIFFERENT LAND USE SYSTEMS ON POTENTIAL OF CARBON SEQUESTRATION

4.2.1 Above ground biomass carbon (Table 4.2)

Land use systems. Critical appraisal of the data of indicated that bael + pearl millet / bael + lentil (T₁₁) agri-horti system was having significantly highest above ground biomass carbon (17.50 t ha⁻¹) as compared to other treatments. This was followed by amla + pearl millet / amla + lentil (T₁₀), custard apple + pearl millet - lentil (T₈) , guava + pearl millet / guava + lentil (T₇) respectively out of which amla + pearl millet / amla + lentil (T₁₀) and custard apple + pearl millet - lentil (T₈) remained statistically at par with each other, whereas, pure orchard karonda (T₃) recorded the lowest above ground biomass carbon (4.00 t ha⁻¹) among all the treatments.

4.2.2 Below ground biomass carbon (Table 4.2)

Land use systems. Perusal of data indicated that among the agroforestry systems, combinations of bael + pearl millet / beal + lentil produced the highest below ground biomass carbon (4.55 t ha⁻¹), while the lowest was found in (T₉) i.e. karonda + grasses / karonda + grasses (1.56 t ha⁻¹). Further, among the pure orchards beal (T₅) showed the highest below ground carbon sequestration (2.34 t ha⁻¹) and the lowest was found with (T₃) i.e. pure karonda (1.04 t ha⁻¹).

4.2.3 Total biomass carbon (Table 4.2)

Land use systems. Critical appraisal of the data produced that bael + pearl millet / beal + lentil (T₁₁) agri-horti systems produced significantly higher total biomass carbon (22.05 t ha⁻¹) as compared to other treatments. This was followed by amla + pearl millet / amla + lentil (T₁₀), custard apple + pearl millet - lentil (T₈) , guava + pearl millet / guava + lentil (T₇) respectively out of which amla + pearl millet / amla +

lentil (T₁₀) and custard apple + pearl millet -lentil (T₈) remained statistically at par with each other, whereas, pure orchard karonda (T₃) recorded the lowest total biomass carbon (5.04 t ha⁻¹) among all the treatments.

Table4.2 Effect of different land use system on amount and rate of carbon sequestration at RGSC, BHU, Barkachha, Mirzapur.(U.P.)

Treatments		Biomass carbon			
		Above ground (t ha ⁻¹)	Below ground (t ha ⁻¹)	Total (t ha ⁻¹)	Rate (t ha ⁻¹ yr ⁻¹)
<i>Land use systems (S)</i>					
T ₁ -	Pure guava orchard	4.14	1.09	5.23	0.66
T ₂ -	Pure custard apple orchard	6.50	1.69	8.19	1.03
T ₃ -	Pure karonda orchard	4.00	1.04	5.04	0.63
T ₄ -	Pure amla orchard	7.05	1.84	8.89	1.11
T ₅ -	Pure bael orchard	9.00	2.34	11.34	1.42
T ₆ -	Pure agriculture(pearl millet - lentil)	8.50	2.21	10.71	1.34
T ₇ -	Guava + pearl millet/guava +lentil	12.50	3.25	15.75	1.97
T ₈ -	Custard apple + pearl millet /custard apple+Lentil	15.00	4.07	19.07	2.39
T ₉ -	Karonda + grasses /karonda+ grasses	6.00	1.56	7.56	0.95
T ₁₀ -	Amla + pearl millet /amla+lentil	15.50	4.04	19.54	2.44
T ₁₁ -	Bael + pearl millet /bael+lentil	17.50	4.55	22.05	2.76
SEm±		0.60	0.51	0.55	0.37
CD (P=0.05)		1.76	1.51	1.62	1.08

4.2.4 Rate of carbon sequestration (Table 4.2)

Land use systems. Perusal of data indicated that among the agroforestry systems, combinations of bael + pearl millet / beal + lentil produced the highest rate of carbon sequestration (2.76 t ha^{-1}), while the lowest was found in (T₉) i.e. karonda + grasses / karonda + grasses (0.95 t ha^{-1}). Further among the pure orchards beal (T₅) showed the highest rate of carbon sequestration (1.42 t ha^{-1}) and the lowest was found with pure karonda (T₃) (0.63 t ha^{-1}).

4.2.5 Amount of CO₂ sequestration (Table 4.3)

Land use systems. Among the agroforestry systems, combinations of bael + pearl millet / beal + lentil showed the highest amount of CO₂ sequestration (80.92 t ha^{-1}), while the lowest was found in (T₉) i.e. karonda + grasses / karonda + grasses (27.75 t ha^{-1}). Further, among the pure orchards beal exhibited showed the highest amount of CO₂ sequestration (41.62 t ha^{-1}) and the lowest was found with pure karonda (T₃) (18.50 t ha^{-1}).

4.2.6 Rate of CO₂ sequestration (Table 4.3)

Land use systems. Critical appraisal of the data indicated that bael + Pearl millet / bael+lentil (T₁₁) agri-horti systems showed significantly higher rate of CO₂ sequestration (10.13 t ha^{-1}) as compared to other treatments. This was followed by amla + pearl millet / amla+ lentil (T₁₀), custard apple + pearl millet -lentil (T₈) , guava + pearl millet / guava + lentil (T₇) respectively out of which amla + pearl millet / amla+ lentil (T₁₀) and custard apple + pearl millet -lentil (T₈) remained statistically at par with each other, whereas, pure orchard karonda (T₃) recorded the lowest rate of CO₂ sequestration (2.31 t ha^{-1}) among all the treatments.

Table 4.3 Effect of different land use systems on amount and rate of CO₂ sequestration and carbon credit at RGSC, BHU, Barkachha, Mirzapur.

Treatments	CO ₂ sequestration		Carbon credit (Rs.ha ⁻¹ yr ⁻¹)
	Amount(t ha ⁻¹ of the total age-8 yrs)	Rate(t ha ⁻¹ yr ⁻¹)	
<i>Land use systems (S)</i>			
T ₁ - Pure guava orchard	19.19	2.42	4356.00
T ₂ - Pure custard apple orchard	30.06	3.78	6804.00
T ₃ - Pure karonda orchard	18.50	2.31	4158.00
T ₄ - Pure amla orchard	32.63	4.07	7326.00
T ₅ - Pure bael orchard	41.62	5.21	9378.00
T ₆ - Pure agriculture(pearl millet - lentil)	39.31	4.92	8856.00
T ₇ - Guava + pearl millet/guava +lentil	57.80	7.23	13014.00
T ₈ - Custard apple + pearl millet /custard apple+Lentil	69.99	8.77	15786.00
T ₉ - Karonda + grasses /karonda+ grasses	27.75	3.49	6282.00
T ₁₀ - Amla + pearl millet /amla+lentil	71.71	8.95	15110.00
T ₁₁ - Bael + pearl millet /bael+lentil	80.92	10.13	18234.00
SEm±	0.57	0.42	444.56
CD (P=0.05)	1.70	1.25	1311.26

Carbon credit was calculated as per the following formula:

Rate(t ha⁻¹yr⁻¹) x 30 US \$ x 60 Indian rupees

One ton CO₂ sequestered per year = One carbon credit

4.3 CARBON CREDIT UNDER DIFFERENT LAND USE SYSTEMS (TABLE 4.3)

Land use systems. Critical appraisal of data showed that carbon credit ($\text{Rs ha}^{-1}\text{yr}^{-1}$) varied appreciably under different land use systems. Maximum carbon credit ($\text{Rs } 18,234 \text{ ha}^{-1}\text{yr}^{-1}$) was estimated at bael + pearlmillet / bael+lentil (T_{11}) among all the treatments. This was followed by custard apple + pearlmillet / custard apple + lentil (T_8), amla+pearlmillet/ amla+lentil(T_{10}), guava+pearlmillet/guava+lentil(T_7), pure orchard bael orchard(T_5), agriculture crops(T_6), pure amla orchard (T_4), pure custard apple orchard (T_2), karonda + grasses / karonda + grasses(T_9), pure guava orchard (T_1), pure karonda(T_3) respectively in descending order.

4.4 EFFECT ON SOIL PHYSIC - CHEMICAL PROPERTIES UNDER DIFFERENT LAND USE SYSTEMS

4.4.1 Soil organic carbon (%) (Table 4.4)

It was evidently clear from the data presented in the table no. 4.4 that organic carbon (%) was significantly influenced by different land use systems and soil depth.

Land use systems. Significantly maximum soil organic carbon (0.40%) was recorded in karonda + grasses / karonda+grasses(T_9) and this was followed by amla + pearlmillet / amla+lentil (0.38%)(T_{10}) agri-horti system and beal+ pearlmillet / beal+lentil (T_{11})(0.37%) agri-horti system. Minimum soil organic carbon (0.29%) was observed in pure karonda orchard (T_3).

Soil depth (cm). Statistical analysis of data represents that the higher soil organic carbon (0.37 %) was estimated at the depth of 0-15 cm (D_1) and lower soil organic carbon (0.31 %) was estimated at the depth of 15-30cm (D_2).

Table 4.4 Effect of different land use system and soil depth on soil organic carbon (%), bulk density (g cm^{-3}), soil organic carbon density (t ha^{-1}) and total soil carbon stock (soil + leaf litter) (t ha^{-1}) at RGSC, BHU, Barkachha, Mirzapur.

Treatments	Soil organic carbon(%)	Bulk density(g cm^{-3})	Soil organic carbon density(t ha^{-1})	Total soil carbon stock (soil+ leaf litter)(t ha^{-1})
<i>Land use systems (S)</i>				
T ₁ - Pure guava orchard	0.33	1.37	6.65	13.52
T ₂ - Pure custard apple orchard	0.32	1.34	6.41	13.01
T ₃ - Pure karonda orchard	0.29	1.32	5.92	12.00
T ₄ - Pure amla orchard	0.33	1.42	7.00	14.48
T ₅ - Pure bael orchard	0.33	1.43	6.92	14.06
T ₆ - Pure agriculture(pearl millet - lentil)	0.31	1.46	6.66	13.77
T ₇ - Guava + pearl millet/ guava +lentil	0.37	1.38	7.51	15.65
T ₈ - Custard apple + pearl millet /custard apple+Lentil	0.34	1.35	6.88	14.35
T ₉ - Karonda + grasses /karonda+ grasses	0.40	1.34	8.04	16.61
T ₁₀ - Amla + pearl millet /amla+lentil	0.38	1.36	7.64	16.32
T ₁₁ - Bael + pearl millet /bael+lentil	0.37	1.27	6.94	14.55
S _{Em} ±	0.03	0.01	0.30	0.37
CD (P=0.05)	0.08	0.06	0.87	1.08
<i>Soil depth (cm) (D)</i>				
D ₁ - 0-15	0.37	1.32	7.25	-
D ₂ - 15-30	0.31	1.41	6.67	-
S _{Em} ±	0.06	0.01	0.71	-
CD(P=0.05)	0.18	0.05	2.04	-
S x D	NS	S	S	-

4.4.2 Bulk density (g cm^{-3}) (Table 4.4)

Land use systems. Statistical data represents that maximum bulk density (1.46 g cm^{-3}) was obtained from agriculture crops (T_6) among all other land use systems. However, minimum bulk density (1.27 g cm^{-3}) was recorded in bael + pearl millet /bael+ lentil (T_{11}) agri-horti systems .

Soil depth (cm).(Table 4.4) Statistical analysis of data showed that the significantly higher bulk density (1.41 g cm^{-3}) was estimated at 15-30 cm depth (D_2) and lower bulk density (1.32 g cm^{-3}) was estimated at 0-15cm depth (D_1).

Table shows that bulk density was significantly influenced by two-way interaction between land use systems and soil depth. Data presented in the table 4.5 showed that all the land use systems at each soil depth depicted significantly higher bulk density by D_2T_6 treatment combination, as compared to all other land use systems and showed at par results with D_2T_5 treatment combination. Moreover, data showed that significantly lower bulk density by D_1T_{11} treatment combination.

Table 4.5 Effect of interaction between different land use systems and soil depth on soil bulk density in R.G.S.C., BHU, Barkachha, Mirzapur(U.P.)

Land use system (S)	Soil bulk density(t ha ⁻¹)	
	Soil depth (D)	
	(0-15cm)	(15-30cm)
T ₁ - Pure guava orchard	1.36	1.37
T ₂ - Pure custard apple orchard	1.32	1.35
T ₃ - Pure karonda orchard	1.31	1.32
T ₄ - Pure amla orchard	1.40	1.43
T ₅ - Pure bael orchard	1.42	1.44
T ₆ - Pure agriculture(pearl millet - lentil)	1.45	1.47
T ₇ - Guava + pearl millet /guava +lentil	1.36	1.39
T ₈ - Custard apple + pearl millet /custard apple+Lentil	1.32	1.38
T ₉ - Karonda + grasses /karonda+ grasses	1.33	1.35
T ₁₀ - Amla + pearl millet /amla+lentil	1.36	1.37
T ₁₁ - Bael + pearl millet /bael+lentil	1.24	1.30
Mean	1.35	1.38
SEm±		0.01
LSD (P= 0.05) for interaction SxD		0.05

4.4.3 Soil organic carbon density (t ha^{-1}) (Table 4.4.)

Land use systems. Critical appraisal of data showed that total carbon density (t ha^{-1}) varied appreciably under different land use systems. Maximum soil organic carbon density (8.04 t ha^{-1}) was recorded in karonda based horti-pasture system (T_9), and this was followed by amla based agri-horti system (T_{10}), guava based agri-horti system (T_7), pure bael orchard (T_5), bael based agri-horti system (T_{11}), custard apple based agri-horti system (T_8), pure agriculture (T_6), pure guava orchard (T_1), pure custard apple orchard (T_2) respectively. While, minimum soil organic carbon density (5.92 t ha^{-1}) was recorded in pure karonda orchard (T_3), which was found to be significantly minimum than all other land use systems.

Soil depth (cm) Results showed that soil organic carbon density for soil depth did not significantly differ under both 0-15cm and 15-30cm depth.

Data presented in table no. 4.6 revealed that soil organic carbon stock was significantly influenced by two-way interaction between land use systems and soil depth. Interaction effect due to land use systems at each soil depth showed higher (8.77 t ha^{-1}) soil organic carbon stock under D_1T_7 treatment combination and lower (5.54 t ha^{-1}) soil organic carbon stock under D_2T_3 treatment combination. Rest of the treatment combinations did not show any significant difference.

4.4.4. Total soil carbon stock (soil + leaf litter) (t ha^{-1}) (Table 4.4)

Land use systems. Critical appraisal of data showed that total carbon stock in the soil (t ha^{-1}) varied appreciably under different land use systems. Maximum total soil carbon stock (16.61 t ha^{-1}) was recorded under karonda based horti-pasture system (T_9) which was statistically at par with pure amla based agri-horti system (T_{10}) and guava + pearl millet / guava + lentil (T_7). Minimum total soil carbon stock (12 t ha^{-1}) was recorded under pure karonda orchard (T_3) which was found to be significantly lower than all other land use systems.

Table 4.6 Effect of interaction between different land use systems and soil depth on soil organic carbon density in R.G.S.C.,BHU, Barkachha, Mirzapur(U.P.)

Land use systems (S)	Soil organic carbon density(t ha ⁻¹)	
	Soil depth (D)	
	(0-15cm)	(15-30cm)
T ₁ - Pure guava orchard	7.14	6.17
T ₂ - Pure custard apple orchard	6.53	6.28
T ₃ - Pure karonda orchard	6.29	5.54
T ₄ - Pure amla orchard	7.14	6.86
T ₅ - Pure bael orchard	7.09	6.75
T ₆ - Pure agriculture(pearl millet - lentil)	6.53	6.79
T ₇ - Guava + pearl millet/guava +lentil	8.77	6.26
T ₈ - Custard apple + pearl millet /custard apple+Lentil	7.13	6.62
T ₉ - Karonda + grasses /karonda+ grasses	8.18	7.90
T ₁₀ - Amla + pearl millet /amla+lentil	7.92	7.35
T ₁₁ - Bael + pearl millet /bael+lentil	7.06	6.82
Mean	7.25	6.67
SEm±		0.22
LSD (P= 0.05) for interaction SxD		0.62

4.5 EFFECT OF SURFACE LEAF LITTER UNDER DIFFERENT LAND USE SYSTEMS

4.5.1 Fresh weight of surface leaf litter (t ha^{-1})(Table 4.7)

Land use systems. The results revealed highest fresh weight of surface leaf litter (2.91 t ha^{-1}) under amla + pearl millet / amla+ lentil (T_{10}) and it was followed by bael+ pearl millet / bael+lentil (T_{11}) agri-horti system, while the lowest fresh weight of surface leaf litter (0.54 t ha^{-1}) was found with pure karonda orchard(T_3) .

4.5.2 Dry matter accumulation of surface leaf litter (t ha^{-1})(Table 4.7)

Land use systems. Data clearly showed that the maximum dry matter accumulation of surface leaf litter (2.10 t ha^{-1}) was obtained under amla + pearl millet / amla+ lentil (T_{10}), followed by guava based agri-horti system(T_6) and custard apple+ pearl millet - lentil (T_8), while the lowest dry weight of surface leaf litter (0.34 t ha^{-1}) was found in pure karonda orchard (T_3) to other all land use systems.

4.5.3 Total biomass carbon by surface leaf litter (t ha^{-1})(Table 4.7)

Land use systems. The highest biomass carbon of surface leaf litter (1.05 t ha^{-1}) was found under amla + pearl millet / amla+ lentil (T_{10}) after which it was observed to be in the order of $T_{11} > T_7 > T_8 > T_9 > T_4 > T_6 > T_5 > T_1 > T_2 > T_3$ while pure orchard karonda(T_3) produced the lowest biomass carbon of leaf litter.

Table 4.7 Influence of different land use systems on leaf litter – its accumulation (fresh and dry weight basis) and total biomass carbon by leaf litter at RGSC, BHU, Barkachha, Mirzapur district (U. P.).

Treatments	Leaf litter accumulation		Total biomass carbon by leaf litter(t ha ⁻¹)
	Fresh (t ha ⁻¹)	Dry matter(t ha ⁻¹)	
<i>Land use systems (S)</i>			
T ₁ - Pure guava orchard	0.64	0.41	0.21
T ₂ - Pure custard apple orchard	0.6	0.40	0.20
T ₃ - Pure karonda orchard	0.54	0.34	0.17
T ₄ - Pure amla orchard	1.37	0.95	0.48
T ₅ - Pure bael orchard	0.65	0.43	0.22
T ₆ - Pure agriculture(pearl millet - lentil)	1.24	0.92	0.46
T ₇ - Guava + pearl millet/guava +lentil	1.88	1.23	0.62
T ₈ - Custard apple + pearl millet /custard apple+Lentil	1.84	1.20	0.60
T ₉ - Karonda + grasses /karonda+ grasses	1.78	1.05	0.53
T ₁₀ - Amla + pearl millet /amla+lentil	2.91	2.10	1.05
T ₁₁ - Bael + pearl millet /bael+lentil	1.93	1.35	0.68
SEm±	0.24	0.02	0.02
CD (P=0.05)	0.71	0.07	0.05

4.6 ECONOMIC ANALYSIS

Economic analysis of different land use systems at R.G.S.C, BHU, Barkachha, Mirzapur, Uttar Pradesh was deal with in this section under the following sub heads:

4.6.1 Total cost of cultivation (Rs ha⁻¹yr⁻¹)

*Land use systems.*A perusal of the data presented in the table 4.8 revealed that total cost of cultivation under different land use systems varied appreciably. The cost of cultivation was highest (Rs 50,655.90) in custard apple based agri-horti system (T₈) was followed pure agriculture (T₆), guava based agri-horti system (T₇), amla based agri-horti system (T₁₀), bael based agri-horti system (T₁₁), pure custard apple orchard (T₂), pure amla orchard (T₄), pure guava orchard (T₁), pure bael orchard (T₅), karonda based horti-pasture system (T₉), respectively in the descending order, while minimum cost of cultivation (12,972.74Rs ha⁻¹yr⁻¹) was estimated under pure karonda orchard (T₃)

4.6.2 Gross return (Rs ha⁻¹yr⁻¹)

*Land use systems.*The data in respect of gross return (Rs ha⁻¹yr⁻¹) under different land use systems have been presented in the table 4.8. Among the different of land use systems, gross return was found maximum (Rs1,90,560) in custard apple based agri-horti system (T₈), which was closely followed by amla based agri- horti system(T₁₀), guava based agri-horti system (T₇), bael based agri-horti system (T₁₁), pure custard apple orchard (T₂), pure agriculture (T₆), pure amla orchard (T₄),pure guava orchard(T₁),karonda based horti-pature system (T₉), pure bael orchard(T₅) respectively while minimum gross return (Rs40,000) was found under karonda orchard (T₃) in respective of all other land use systems.

4.6.3 Net return (Rs ha⁻¹yr⁻¹)

Land use systems. Critical appraisal of the data shows that the maximum value of net return (1,39,904.10Rs ha⁻¹yr⁻¹) was recorded under custard apple based agri-horti system (T₈), which was closely followed by amla based agri- horti system(T₁₀), guava based agri-horti system (T₇), bael based agri-horti system (T₁₁), pure custard apple orchard (T₂), pure amla orchard (T₄), pure guava orchard(T₁), pure agriculture (T₆) , karonda based horti-pature system (T₉),pure bael orchard(T₅) respectively, whereas minimum net return (27,027.26Rs ha⁻¹yr⁻¹) was found in pure karonda orchard (T₃).

4.6.4 Total benefit (net profit+ carbon credit) (Rs ha⁻¹yr⁻¹)

Total benefit of different land use systems of R.G.S.C, BHU, Barkachha, Mirzapur, Uttar Pradesh is presented in Table 4.6.

Land use systems. Perusal of the data of table no 4.6 showed maximumtotal benefits (1,55,690.10Rs ha⁻¹yr⁻¹) under custard apple based agri-horti system (T₈), which was closely followed by amla based agri- horti system(T₁₀), guava based agri-horti system (T₈), bael based agri-horti system (T₁₁), pure custard apple orchard (T₂), pure amla orchard (T₄), pure guava orchard(T₁), pure agriculture (T₆) karonda based horti-pature system (T₉),pure bael orchard(T₅) respectively in the descending order, whereas, minimum value of total benefits (31,185.26Rs ha⁻¹yr⁻¹) was found in pure karonda orchard (T₃) as compared to all other land use systems.

Table 4.8 Comparison criteria for economic analysis of different land use systems in experiment duration at RGSC, BHU, Barkachha, Mirzapur district (U.P.)

Treatments	Cost of cultivation (Rs. ha ⁻¹)	Gross return (Rs. ha ⁻¹)	Net return (Rs. ha ⁻¹)	Total benefits (net profit + carbon credits) (Rs. ha ⁻¹)	B: C ratio (%)
<i>Land use systems (S)</i>					
T ₁ - Pure guava orchard	27004.82	86100.00	59095.18	63451.18	2.35
T ₂ - Pure custard apple orchard	36006.26	120000.00	83993.74	90797.74	2.52
T ₃ - Pure karonda orchard	12972.74	40000.00	27027.26	31185.26	2.40
T ₄ - Pure amla orchard	27408.34	91800.00	64391.66	71717.66	2.62
T ₅ - Pure bael orchard	20153.38	61200.00	41046.62	50424.62	2.50
T ₆ - Pure agriculture (pearl millet - lentil)	45204.22	94500.00	49295.78	58151.78	1.29
T ₇ - Guava + pearl millet / guava + lentil	41927.15	159375.00	117447.85	130461.85	3.11
T ₈ - Custard apple + pearl millet / custard apple + Lentil	50655.90	190560.00	139904.10	155690.10	3.07
T ₉ - Karonda + grasses / karonda + grasses	17106.84	66000.00	48893.16	55175.16	3.23
T ₁₀ - Amla + pearl millet / amla + lentil	39613.63	174300.00	134686.37	149796.37	3.78
T ₁₁ - Bael + pearl millet / bael + lentil	36195.32	137580.00	101384.68	119618.68	3.30
SEm±	-	404.52	348.16	373.35	0.40
CD (P=0.05)	-	1193.15	1026.90	1101.23	1.19

4.5.5 Benefits: cost ratio

Total benefit of different land use systems of R.G.S.C, BHU, Barkachha, Mirzapur, Uttar Pradesh is depicted in the table no. 4.6.

Land use systems. The results revealed that maximum benefit : cost ratio (3.78) was observed under amla based agri-horti system (T₁₀), which was closely followed by bael based agri-horti system (T₁₁), karonda based horti-pature system (T₉), guava based agri- horti system(T₇), custard apple based agri-horti system (T₈),pure amla orchard (T₄), pure custard apple orchard (T₂), pure bael orchard(T₅), pure karonda orchard (T₃), pure guava orchard(T₁),respectively in the descending order under different agri-horti systems ,while, minimum (1.29), benefit: cost ratio was found in pure agriculture (T₆) based land use system.



The investigations on “Evaluation of carbon sequestration potential under different land use systems” were carried out in, RGSC, BHU, Barkachha, Mirzapur district of Uttar Pradesh (India) during the years of 2014-2015. The present study is a maiden attempt to know the biomass and carbon stocks, carbon mitigation potential and economic return from different agri-horti systems at R.G.S.C, BHU. This chapter has been devoted to examine the results of the current study based on logical arguments in the light of scientific evidences wherever available in the literature. The results have been proved by establishing the cause and effect relationship among them to derive a fruitful conclusions under the following heads and subheads:

5.1 Effect of land use systems

5.1.1 Biomass production levels under different land use systems

Land use system has direct influence on the micro-climate of the soil and plant which will affect the different growth stages of the crop and ultimately productivity. Results revealed that the biomass viz., above, below and total biomass was significantly influenced due by the land use systems at R.G.S.C. All the arable land use with agroforestry systems showed higher biomass accumulation than non-arable land use systems (Goswami *et al.* 2014). The maximum above ground biomass accumulation was recorded in bael + pearl millet/bael + lentil (T₁₁) agri-horti system followed by amla + pearl millet/aml + lentil (T₁₀) custard apple + pearl millet/custard apple + lentil (T₈) guava + pearl millet/guava + lentil (T₇). Swamy *et al.* (2003) reported that in nutrient rich soil, more biomass is allocated to the above ground parts.

Reports for above ground biomass were also presented by Chavan and Rasal (2012), Bohre *et al.* (2014) and Yadava (2011). The below ground biomass, in general, follows the same trend as that of above ground biomass (Pande, 2005).

Koul and Panwar (2008) observed that stem contributed more than branch and least contribution was made by the leaf in case of agri-horti system.

Component of the above ground biomass of tree viz., stem, branch wood and leaf depends are affected by a number of factors like, growth habit of the species, site quality, soil on which trees are growing, age of the tree, management practices, intercultural operations, moisture conservation and its interaction with below ground biomass, which in turn contributes to make it taller and increase diameter at breast height of poplar trees by (Yadav 2012). The biomass of an agroforestry systems depends on a number of factors including the growth habit of species, site quality, age, management practice and the interaction between trees and under store crops (Jana *et al.* 2009, Kanime *et al.* 2013)

5.1.2 Rate of biomass accumulation ($\text{t ha}^{-1}\text{yr}^{-1}$)

At agriculture farm of RGSC, the bael based agri-horti systems exhibited the maximum rate of biomass accumulation ($5.51 \text{ t ha}^{-1}\text{yr}^{-1}$). With the increase of age in woody components the rate of biomass accumulation ($\text{t ha}^{-1}\text{yr}^{-1}$) decreases.

5.2 Carbon sequestration potential of different land use systems

Carbon mitigation potential of agroforestry systems is dependent on the tree density, age, structure and C concentration in different components (Oelbermann *et al.* 2004, Swamy and Puri 2005; Kanime *et al.* 2013).

Data revealed that all the traits of biomass i.e. above ground carbon, below ground carbon and total carbon were significantly influenced due by the land use systems. In the present ecosystem under maximum above ground carbon (17.50 t ha^{-1}) sequestration was exhibited by bael based system, which was closely followed by amla based agri-horti system (T_{10}) > custard apple based agri-horti system (T_8) > guava based agri-horti system (T_7) > pure bael orchard (T_5) > pure agriculture (T_6) > pure amla orchard (T_4) > pure custard apple orchard (T_2) > karondha based horti-pasture system (T_9) > pure guava orchard (T_1) > pure karondha orchard (T_3).

The below ground carbon sequestration and total carbon sequestration in general, followed more or less same trend as depicted by the above ground carbon sequestration. Only slight variation was detected in annually based cropping systems, which can be attributed to their variation in carbon allocation pattern to aerial and below ground component (Oelbermann *et al.* 2004, Swamy and Puri 2005; Kanime *et al.* 2013).

Data clearly indicated that bael + pearl millet/bael + lentil (T_{11}) agri-horti system recorded the highest total carbon sequestration (22.05 t ha^{-1}) followed amla + pearl millet/amlal + lentil (T_{10}) agri-horti system (19.54 t ha^{-1}) and custard apple + pearl millet/custard apple + lentil (T_8) agri-horti system (19.07 t ha^{-1}), whereas, pure karonda orchard (T_3) showed the lowest total carbon sequestration (5.04 t ha^{-1}). Similar above ground carbon in vegetation ranging from 6.51 (2004) to 8.95 (2007) Mg ha^{-1} with 87%, 9% and 4% of the total C stored in culm, branch and leaf respectively by traditional home garden system has was also reported by Singh and Pandey (2011). Some trend in the rate of C sequestration and total carbon sequestration in agroforestry systems was also reported by Chavan and Rasal (2012), Bohre *et al.* (2011), Koul and Panwar (2008), Rathore and Jasrai (2013).

The variability in the productivity of agroforestry system was recorded by Albrecht and Kandji (2003). The amount of carbon sequestered largely depends on the kind of agroforestry system, management practices adopted and soil and climate of the region (Prasad *et al.* 2012).

Carbon sequestration in agroforestry systems can be broadly divided into sequestration in above ground and below ground plant parts. The above ground carbon sequestration rates in some major agroforestry systems around the world are highly variable in nature (Nair *et al.* 2010) and differ greatly depending on a number of factors like the agro - climatic condition, the type of system, site quality, previous land use, management practices adopted etc and agroforestry systems on the arid, semi-arid and degraded sites have a lower carbon sequestration potential than those on fertile humid sites.

5.2.1 Rate of C and CO₂ sequestration (t ha⁻¹yr⁻¹)

The rate of C and CO₂ sequestration, removal and retention follows the same trend as that of the above, below and total biomass carbon sequestration and rate of biomass production. This is because the rate of C and CO₂ sequestrations are simply a derived from the rate of biomass production. The highest rates of C and CO₂ sequestration (2.76 t ha⁻¹ yr⁻¹) and (10.13 t ha⁻¹ yr⁻¹) were found under bael based (T₁₁) agri-horti system. This was in conformity with findings of Barakas and Aune (2011) and Kanime *et al.* (2011).

5.3 Soil Physico-chemical properties

5.3.1 Soil organic carbon

It was crystal clear from the data that organic carbon (%) varied significantly under different land use systems and soil layers in the

experiment. Maximum soil organic carbon (0.40 %) was found in the karonda based horti-pasture system (T₉), which, however remained statistically at par with the organic carbon content of the amla based agri-horti system (T₁₀) but differed significantly from all other land use systems. Lal *et al.* (1998) reported significantly higher organic carbon in forest and fruit tree based land use systems than in annual cropping systems. Low soil organic carbon under arable land use systems may be attributed to the intensive cropping in annual based land use systems.

Mandal *et al.* (2007) also reported that the rate of decomposition of SOM is generally higher in tropical than in temperate climate. However, crop species also play an important role in maintaining SOC pools, through the quality and quantity of the residues that were returned to the soil.

The carbon fixed by the plant is the primary source of organic matter input into the soil, which provides substrate for microbial process and accumulation of soil organic matter. The below ground allocation of photosynthates is also an important factor for improving soil organic carbon content (Kaur *et al.*, 2002).

5.2.2 Bulk density (g cm⁻³)

The data presented in the table 4.4 showed that the bulk density (g cm⁻³) varied significantly under different land use systems and soil layers.

The bulk density under different land use systems of agriculture farm at RGSC followed the trend of agriculture crops (T₆) > pure bael orchard (T₅) > pure amla orchard (T₄) > guava based agri-horti system (T₇) > pure guava orchard (T₁) > amla based agri-horti system (T₁₀) > custard apple based agri-horti system (T₈) > pure

custard apple orchards (T₂) and karonda based horti-pasture system (T₉) > pure karonda orchard (T₃) > bael based agri-horti system (T₁₁), respectively. John (2004) also reported that soil bulk density in wheat ranged from 1.33 g cm⁻³ at 0-15 cm to 1.41 g cm⁻³ at 15-30 cm soil depth, while, Sharma (2004) in a study on some physico-chemical properties of soil in wheat and reported that the bulk density ranged from 1.20 to 1.52 mg cm⁻³.

Similarly, Mishra *et al.* (2014) reported that in the surface soil layer (0–15 cm), the bulk density (BD) decreased under agroforestry, horticultural plantations and rice–wheat systems over the uncultivated barren sodic soil. Under the *Casuarina equisetifolia* L. the lowest BD (1.36 mg m⁻³) was observed, whereas the highest BD of 1.52 mgm⁻³ was recorded under the uncultivated barren sodic soil.

The higher value of bulk density in the soils can also be ascribed to lower soil organic carbon content in these systems. These findings were in agreement with the findings of Sharma (2004).

5.2.3 Soil organic carbon stock

Soil organic carbon stock was determined by multiplying organic carbon with soil weight for a particular depth. It was evident from the data presented in the table 4.4 that soil organic carbon was significantly influenced by land use systems.

Maximum soil organic carbon density was recorded in karonda based horti-pasture system (T₉) (8.04 t ha⁻¹) cropping pattern, which remained statistically at par with all woody component based land use systems but was found significantly higher than the agriculture crop based land use system. This might have happened because of enhanced accumulation of leaf litter under the tree and fruit based agri-horti systems. The abundant leaf litter or pruned biomass

returned to the soil, (combined with decay of roots) contributed to the improvement of organic matter content under complex land use systems (Beer *et al.*, 1990). The findings were similar to those obtained by a few other worker like Koul and Panwar, (2012) and Odiwe *et al.*(2012).

It was also evident from data that soil organic carbon density declines appreciably from D₁ (0-15 cm) to D₂ (15-30 cm) soil layer. The increase or decrease in the soil organic carbon pool is associated with the bulk density and organic carbon content of the soil at a particular depth. The higher amount of soil organic carbon stock on the surface layer i.e. 0-15 cm soil depth might be explained by the fact that there was continuous accumulation of leaf litter on the surface, which kept on decomposing and thus enriched the upper soil layer (0-15 cm) continuously. These results were in line with the findings of Woome and Palm (1998), Chauhan and Gupta *et al.* (2011). Further among the four land uses (forest, grassland, horticulture, agriculture) on SOC stock as well as concentration was found to be the highest at soil depth (0-100 cm) in temperate and the lowest in subtropical climate in the same soil (Singh *et al.* 2011). Ghimire *et al.* (2008) also reported that soil (0-50 cm depth) under no-tillage retained higher carbon than conventional tillage treatment.

5.2.4 Soil organic carbon pool inventory (t ha⁻¹)

The carbon pool inventory of land use system was prepared by adding soil organic stock and plant carbon stock expressed as t ha⁻¹.

In the agriculture farm, maximum soil organic pool (16.61 t ha⁻¹) in 0-30 cm layer was found in karonda based horti pasture system (T₉) followed by the treatments T₁₀, T₇, T₁₁, T₁₄, T₈, T₅, T₆, T₁, T₂ and T₃, respectively in the descending order. The total soil organic

carbon stock observed in the karonda based horti pasture system was found to be 2.1 times higher than other land use systems. This result was in conformity with the findings of Singh *et al.* (2011) and Koul and Panwar (2012).

In agroforestry systems the carbon is stored in soil up to 1 meter depth (Nair *et al.* 2010). Carbon sequestered in agroforestry systems depends on the quantity and quality of biomass added through trees and soil parameters such as soil structure and aggregation. In a poplar system an increase in soil carbon and higher carbon content was observed in 0-30 cm depth in sandy clay in comparison to loamy sand and about 69% of soil carbon in the profile remained confined to the upper 40 cm soil layer. A mix of forestry and crop fields is a promising option to enhance C sequestration in soils.

5.4 Carbon credits (Rs ha⁻¹yr⁻¹)

Carbon credits expressed in term of Rs ha⁻¹yr⁻¹ were calculated based on the quantum of CO₂ absorbed from the atmosphere and locked in the form of biomass. One ton of CO₂ fixed in biomass is equal to 1 carbon credit and the value of one carbon credit is 30 US \$.

In the agriculture farm of RGSC, critical appraisal of data showed that carbon credit (Rs ha⁻¹yr⁻¹) varied appreciably under different land use systems. Maximum carbon credit (Rs 18,234 ha⁻¹ yr⁻¹) was evaluated under bael + pearl millet/bael + lentil system (T₁₁), and this was followed by custard apple + pearl millet/ custard apple + lentil (T₈), amla + pearl millet/amlam + lentil (T₁₀), guava + pearl millet/guava + lentil (T₇), pure orchard bael orchard (T₅), agriculture crops (T₆), pure amla orchard (T₄), pure custard apple orchard (T₂), karonda + grasses / karonda + grasses (T₉), pure guava orchard (T₁), pure karonda (T₃), respectively in descending order.

From above results, it can be inferred that more carbon credit can be realized from all fruit based agroforestry systems in both valley and mountainous ecosystem. The amount of carbon credits which can be realized from a land use system is the function of rate of CO₂ capturing ability of plants and its locking in the form of biomass. The rate of CO₂ capturing ability in the form of woody biomass in fruit based system is more because they are intensively managed at the same time only a small fraction of biomass is removed in the form of pruned wood and fruit yield.

5.5 Economic returns

The data for total cost, gross returns, net profit, benefit-cost ratio and total benefit (net profit + carbon credit), which were realized from different land use systems was presented in table no. 4.6. Gross returns, total expenses, net profit, cost-benefit ratio and total benefit (net profit + carbon credits), obtained from different land use systems as well as pure orchard were markedly higher than the annual cropping systems. Maximum net return (1,39,904.10 Rs ha⁻¹yr⁻¹) maximum gross return (1,90,560 Rs ha⁻¹yr⁻¹), maximum cost of cultivation (50,655.90 Rs ha⁻¹yr⁻¹) and total benefit (1,55,690.10 Rs ha⁻¹yr⁻¹) were recorded under custard apple based agri-horti system (T₈) while the highest benefit-cost ratio (3.78%) were recorded in the amla based agri-horti system(T₁₀). The benefit-cost ratio (1.29 %) was the lowest in pure agriculture systems because of the maximum input.

From the above results it was clear that the net return, net profit and total benefits were higher in the land use systems involving fruit trees like custard apple, amla and guava in association with the agriculture crop viz., pearl millet and lentil. The higher per unit market prices of fruit along with higher yield because of higher

intensity of management coupled with other facilities are some of the reasons, which can be assigned to the higher return from them than the annual crop based land use systems. It was also clear from the results that fruit based agroforestry system and pure orchards gave higher returns at agriculture farm of RGSC than the agriculture crops involving cereals and pulse. The reason for the same is again the higher unit market prices of fruits, higher suitability of fruit trees in prevailing climatic conditions. Newaj and Rai (2005) also reported higher B : C ratio (2:61) by amla based agroforestry system under rainfed conditions. Furthermore, Das et al. (2011) reported that amla + turmeric gave a higher value (6:29) followed by amla + ginger (3:44) and amla + arbi (3:20) gave a B:C ratio of 6.29, 3.44 and 3.20 respectively.



A field experiment entitled “Evaluation of carbon sequestration potential of different land use systems” was carried out at RGSC, BHU, Barkachha, Mirzapur districts of Uttar Pradesh during 2014-2015. The experiment was carried out through 2 experiments. The first one was conducted in a Randomized Complete Block Design (RCBD) with 11 treatments (land use system) and 3 replications, while the second trial was a factorial experiment laid out in Randomized Complete Block Design with 2 factors and 3 replications. For conducting the experiment different land use systems of agriculture farm at RGSC were selected.

The data was recorded on above ground biomass of all the land use systems. Crop, shrubs and grass biomass was estimated by using 1x1 m² spacing. Crop and fruit yield of trees were either determined on unit area basis. Litter biomass was measured in 1x1 m² plot size. Soil attributes viz., bulk density, organic carbon were also determined and these were used for preparing the carbon pool inventory and soil organic carbon density. These soil samples were taken from 0- 15 cm and 15-30 cm soil depth. The salient findings of the experiment are summarized as under:

- ❖ The results of the experiment at agriculture farm of RGSC revealed that different land use systems had significant influence on the accumulation of above, below and total biomass and rate of biomass accumulation. The maximum above ground biomass (35 t ha⁻¹), below ground biomass (9.10 t ha⁻¹), total biomass (44.10 t ha⁻¹) and rate of biomass (5.51 t ha⁻¹ yr⁻¹) by bael + pearl millet/bael + lentil (T₁₁) agri-horti system was found among the different land use systems.

- ❖ The results of the experiment at RGSC revealed that different land use systems had significant influence on the above, below and total biomass carbon and rate of carbon sequestration. The maximum above ground carbon biomass (17.50 t ha^{-1}), below ground carbon biomass (4.55 t ha^{-1}), total carbon biomass (22.05 t ha^{-1}) and rate of carbon sequestration ($2.76 \text{ t ha}^{-1}\text{yr}^{-1}$) by bael + pearl millet/bael + lentil (T_{11}) agri-horti system were observed among different land use systems.
- ❖ The maximum amount of CO_2 sequestration (80.92 t ha^{-1}) and the maximum rate of CO_2 sequestration ($10.13 \text{ t ha}^{-1}\text{yr}^{-1}$) were displayed by bael + pearl millet/bael + lentil (T_{11}) agri-horti system.
- ❖ Maximum soil organic carbon (0.40 %) was recorded in the karonda based horti-pasture system, which differed significantly from all other land use systems. The soil organic carbon percent declined from D_1 to D_2 soil layer. The maximum bulk density (1.46 g cm^{-3}) was recorded in agriculture crop (T_6) based land use system, which was found to be significantly higher than all other land use systems.
- ❖ The maximum soil organic carbon stock (8.04 t ha^{-1}) was recorded in the karonda based horti-pasture system, which was found to be significantly higher than all other land use systems between the soil layers, SOC stock in (0-15 cm) layer was found to be significantly higher than that of (15-30 cm) layer.
- ❖ Maximum soil organic pool (16.61 t ha^{-1}) in 0-30 cm layer was found in karonda based horti pasture system (T_9) followed by the treatments T_{10} , T_7 , T_{11} , T_{14} , T_8 , T_5 , T_6 , T_1 , T_2 and T_3 , respectively in the descending order. The total soil organic carbon stock observed in the pure bael orchard was 2.1 times higher than annual cropping system.

- ❖ Carbon credit varied appreciably among different land use systems at RGSC. The maximum carbon credit (18,234Rs. ha⁻¹ yr⁻¹) was recorded in the bael based agri-horti system (T₁₁) and maximum gross returns (Rs1,90560Rs ha⁻¹yr⁻¹) and maximum total cost (50,655.90 Rs ha⁻¹yr⁻¹) were recorded in custard apple based agri-horti system (T₈). Same trend in maximum net return (1,39,904.10Rs ha⁻¹yr⁻¹) and total benefit (1,55,690.10 Rs ha⁻¹yr⁻¹) was also observed in custard apple based agri-horti system (T₈). However benefit-cost ratio was found to be maximum (3.78%) in amla based agri-horti system (T₁₀), while, minimum (1.29%), was found in pure agriculture (T₆).

CONCLUSION

On the basis of above, it can be concluded that at RGSC, BHU, Barkachha, Mirzapur, fruit based land use systems viz., custard, amla, guava, bael based agri-horti system and karonda based horti-pasture system are not only biologically productive but has more carbon density, CO₂sequestration potential, net profit, higher benefit-cost and total benefits than field crops based system. On the other hand, from the carbon mitigation potential and economic point of view land use systems, need to be promoted over the traditional field crops based land use system for realizing better monetary return and environmental benefits.



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APPENDICES

Appendix I. Mean week-wise meteorological data during *kharif* and *rabi*, 2014-2015.

Standard Week No.	Months	Date	Rainfall (mm)	Temperature (°C)		Relative humidity (%)	
				Max.	Min.	Max.	Min.
22	June	01-07		38.86	27.77	80.86	54.00
23		8-14		39.01	28.90	76.43	55.57
24		15-21	6.40	34.99	26.87	85.71	65.57
25		22-28	13.27	36.39	26.39	90.43	72.29
26		29-06	13.74	31.30	25.56	95.71	75.43
27	July	07-13	11.50	34.29	27.19	94.29	73.14
28		14-20	1.95	35.53	27.71	91.29	69.29
29		21-27	19.96	35.19	27.24	90.00	72.71
30		28-03	7.17	32.87	26.10	95.57	75.57
31		04-10	13.73	34.54	26.40	92.86	70.71
32	August	11-17	8.20	33.51	26.01	95.57	71.43
33		18-24	28.73	32.91	25.54	95.71	72.00
34		25-31	16.83	33.46	26.41	94.86	70.00
35	September	01-07	20.50	33.43	25.66	94.86	70.86
36		08-14	3.64	34.63	25.31	92.14	64.86
37		15-21	5.60	35.00	26.13	92.86	68.00
38		22-28	52.60	34.10	25.63	87.43	64.57
39		29-05	13.50	31.67	24.91	93.43	71.29
40	October	06-12	5.71	31.14	24.17	95.57	68.86
41		13-19	0.80	29.96	23.10	94.14	63.43
42		20-26	22.80	30.87	22.11	94.71	67.86
43		27-02		31.41	19.74	92.71	60.00
44	November	03-09		29.94	18.10	88.57	55.00
45		10-16		28.13	13.63	91.86	56.86
46		17-23		28.14	12.53	91.29	55.57
47		24-30		27.91	12.04	94.29	57.57
48	December	01-07		27.51	10.24	91.29	49.43
49		08-14		26.47	10.50	93.29	50.57
50		15-21		24.64	9.59	92.29	57.14
51		22-28		23.10	12.41	92.71	71.86
52		29-04		23.27	10.74	91.86	68.14
1	January	5-11		20.81	9.96	95.14	70.57
2		12-18		16.61	9.89	96.14	84.29
3		19-25	17.60	19.84	11.56	89.00	69.57
4		26-01		21.27	11.24	77.43	66.29
5	February	02-08		23.53	11.07	84.00	54.00
6		09-15	0.20	25.19	11.64	90.43	52.14
7		16-22		22.89	10.90	92.00	59.29
8		23-01	11.60	22.96	14.43	91.00	53.43
9	March	02-08		26.53	14.13	92.29	55.14
10		09-15		30.44	14.77	91.29	55.57
11		16-22		31.49	15.47	93.43	56.00
12		23-29		33.13	18.53	89.71	54.86

Source: Observatory, Krishi Bhawan, Mirzapur

Appendix II. Cost of cultivation (Rs.ha⁻¹) of lentil

S.No.	Operations	Input (Rs.)	Rate (Rs.)	Cost (Rs.)
1	Land preparation			
	(a)Deep ploughing	By Tractor	400	550
	(b)Harrowing and planking	By Tractor	400	800
2	Seed and sowing	seed drill	300	750
	Cost of Seed	30	200	6000
3	Fertilizer			0
	Urea	20	6.4	128
	DAP	50	25	1250
	MOP	0	0	0
4	Weeding	8	200	1600
5	Harvesting	8	200	1600
	Threshing	6	200	1200
6	(a) Threshing by tractor	1 hours	700/hr.	700
7	(b) Labour charge	6	200	1200
	Winnowing	7	200	1400
	Miscellaneous			750
8	Transportation			1000
9	Land revenue 6 months	6	15	90
10	Interest on working capital 3 months		14	2852.70
	Total cost			21870.70

Appendix III. Cost of cultivation (Rs.ha⁻¹) of pearl millet.

S.No.	Operations	Input (Rs.)	Rate (Rs.)	Cost (Rs.)
1	Land preparation			
	(a)Deep ploughing	By Tractor	400	550
	(b)Harrowing and planking	By Tractor	400	550
2	Seed and sowing	seed drill	300	1050
	Cost of Seed	5	200	1000
3	Fertilizer			
	Urea	100	6.4	640
	DAP	40	25	1000
	MOP	30	19.6	588
4	Weeding	15	200	3000
5	Harvesting	15	200	3000
	Threshing	15	200	3000
6	(a) Threshing by tractor	1 hours	700/hr.	700
7	(b) Labour charge	6	200	1200
	Winnowing	8	200	1600
	Miscellaneous			1000
8	Transportation			1500
9	Land revenue 6 months	6	15	90
10	Interest on working capital 3 months		14	2865.52
	Total cost			23333.52

Appendix IV. Cost of cultivation (Rs.ha⁻¹) of pure guava orchard and guava based agri-horti system

Operations	Guava (agri-horti system)			Pure guava orchard		
	Input	Rate (Rs.)	Cost (Rs.)	Input	Rate (Rs.)	Cost (Rs.)
Hoeing	10	200	2000	6	200	1200
Weeding	20	200	4000	10	200	2000
Pruning	22	200	4400	15	200	3000
Fertilizer			0			
FYM	5.12	120	614.4	6.92	120	830.4
		Rs/t			Rs/t	
Urea	61.5	6.4	393.6	83.1	6.4	531.84
DAP	307.5	8.4	2583	415.5	8.4	3490.2
MOP	82	19.6	1607.2	110	19.6	2156
Labour	15	200	3000	5	200	1000
Harvesting	25	200	5000	15	200	3000
Grading	20	200	4000	6	200	1200
Packing	20	200	4000	15	200	3000
Miscellaneous	0	2000	2000	0	600	600
Transportation		3000	3000	0	1500	1500
Land revenue (12 months)	12	15	180	12	15	180
Interest on working capital		14	5148.948	0	14	3316.38
Total cost			41927.148			27004.82

Appendix V. Cost of cultivation (Rs.ha⁻¹) of custard apple and custard apple based agri-horti system

Operations	Custard apple (agri-horti system)			Pure custard apple orchard		
	Input	Rate (Rs.)	Cost (Rs.)	Input	Rate (Rs.)	Cost (Rs.)
Hoeing	15	200	3000	10	200	2000
Weeding	25	200	5000	15	200	3000
Pruning	25	200	5000	20	200	4000
Fertilizer			0			
FYM	5.12	120 Rs/t	614.4	6.92	120 Rs/t	830.4
Urea	61.5	6.4	393.6	83.1	6.4	531.84
DAP	307.5	8.4	2583	415.5	8.4	3490.2
MOP	90	19.6	1764	120	19.6	2352
Labour	20	200	4000	10	200	2000
Harvesting	30	200	6000	18	200	3600
Grading	25	200	5000	15	200	3000
Packing	25	200	5000	18	200	3600
Miscellaneous	0	2000	2400	0	1000	1000
Transportation		3000	3500	0	2000	2000
Land revenue (12 months)	12	15	180	12	15	180
Interest on working capital		14	6220.9	0	14	4421.82
Total cost			50655.9			36006.26

Appendix VI. Cost of cultivation (Rs. ha⁻¹) of karonda and karonda based horti-pasture system

Operations	Karonda (horti-pasture system)			Pure karonda orchard		
	Input	Rate (Rs.)	Cost (Rs.)	Input	Rate (Rs.)	Cost (Rs.)
Hoeing	3	200	600	2	200	400
Weeding	0	0	0	5	200	1000
Pruning	4	200	800	3	200	600
Fertilizer			0			
FYM	1.05	120 Rs/t	126	1.11	120 Rs/t	133.2
Urea	100	6.4	640	111	6.4	710.4
DAP	20	8.4	168	27	8.4	226.8
MOP	20	19.6	392	27	19.6	529.2
Labour	6	200	1200	4	200	800
Harvesting	9	200	1800	8	200	1600
Grading	8	200	1600	5	200	1000
Packing	8	200	1600	6	200	1200
Miscellaneous	0	2000	2400	0	1000	1000
Transportation		3000	3500	0	2000	2000
Land revenue (12 months)	12	15	180	12	15	180
Interest on working capital		14	2100.84	0	14	1593.14
Total cost			17106.84			12972.74

Appendix VII. Cost of cultivation (Rs.ha⁻¹) of amla and amla based agri-horti system

Operations	Amla (agri-horti system)			Pure amla orchard		
	Input	Rate (Rs.)	Cost (Rs.)	Input	Rate (Rs.)	Cost (Rs.)
Hoeing	10	200	2000	6	200	1200
Weeding	18	200	3600	15	200	3000
Pruning	21	200	4200	16	200	3200
Fertilizer						
FYM	2	120 Rs/t	240	2.04	120 Rs/t	244.8
Urea	35.8	6.4	229.12	40.8	6.4	261.12
DAP	95	8.4	798	102	8.4	856.8
MOP	35.8	19.6	701.68	40.8	19.6	799.68
Labour	15	200	3000	10	200	2000
Harvesting	24	200	4800	17	200	3400
Grading	22	200	4400	12	200	2400
Packing	23	200	4600	15	200	3000
Miscellaneous	0	2500	2500	0	1000	1000
Transportation		3500	3500	0	1500	2500
Land revenue (12 months)	12	15	180	12	15	180
Interest on working capital		14	4864.83	0	14	3365.94
Total cost			39613.63			27408.34

Appendix VIII. Cost of cultivation (Rs.ha⁻¹) of bael and bael based agri-horti system

Operations	Bael (agri-horti system)			Pure bael orchard		
	Input	Rate (Rs.)	Cost (Rs.)	Input	Rate (Rs.)	Cost (Rs.)
Hoeing	10	200	2000	4	200	800
Weeding	18	200	3600	10	200	2000
Pruning	21	200	4200	16	200	3200
Fertilizer						
FYM	2	120	240	2.04	120	244.8
		Rs/t			Rs/t	
Urea	4.3	6.4	27.52	5.1	6.4	32.64
DAP	2.2	8.4	18.48	2.5	8.4	21
MOP	4.3	19.6	84.28	5.1	19.6	99.96
Labour	15	200	3000	6	200	1200
Harvesting	20	200	4000	10	200	2000
Grading	19	200	3800	12	200	2400
Packing	23	200	4600	10	200	2000
Miscellaneous	0	2500	2500	0	1000	1000
Transportation		3500	3500	0	1500	2500
Land revenue (12 months)	12	15	180	12	15	180
Interest on working capital		14	4445.04	0	14	2474.98
Total cost			36195.32			20153.38

Appendix IX. Economics of different land use systems at RGSC, BHU, Barkachha, Mirzapur.

Treatment	Average fruit wt (kg/Tree)	No of fruit tree	Total fruit (kg/ha)	Rate of fruit (Rs./kg)	Grain yield (q/ha)	Price (Rs./q)	Straw yield (q/ha)	Price (Rs./q)
T ₁	28	205	5740	15				
T ₂	20	400	8000	15				
T ₃	4	1111	4444	9				
T ₄	25	204	5100	18				
T ₅	10	204	2040	30				
T ₆					2300+1800	10+30	70	250
T ₇	25	205	5740	15	1950+1600	10+30	60	250
T ₈	20	400	8000	15	1950+1400	10+30	55	250
T ₉	4	1111	4444	9	30(bundle)	400	40(bundle)	350
T ₁₀	25	204	5100	18	1950+4800	10+30	60	250
T ₁₁	9	204	1836	30	1950+4800	10+30	60	025

Appendix X. Root : Shoot ratio of different fruit trees

S. No.	Tree	Root : Shoot ratio	Source
1	Custard apple	0.29	IPCC
2	Karonda	0.35	IPCC
3	Anola	0.18	IPCC
4	Guava	0.15	IPCC
5	Bael	0.22	IPCC

